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SCIENTIFIC DIALOGUES,  
INTENDED FOR THE  
INSTRUCTION AND ENTERTAINMENT  
OF  
YOUNG PEOPLE:  
IN WHICH  
THE FIRST PRINCIPLES  
OF  
NATURAL AND EXPERIMENTAL  
PHILOSOPHY  
ARE FULLY EXPLAINED.

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VOL. III. OF HYDROSTATICS.

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“ Conversation, with the habit of explaining the meaning  
“ of words, and the structure of common domestic imple-  
“ ments, to children, is the sure and effectual method of  
“ preparing the mind for the acquirement of science.”

EDGEWORTH'S PRACTICAL EDUCATION.

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*A NEW EDITION, Corrected and Improved.*

London :

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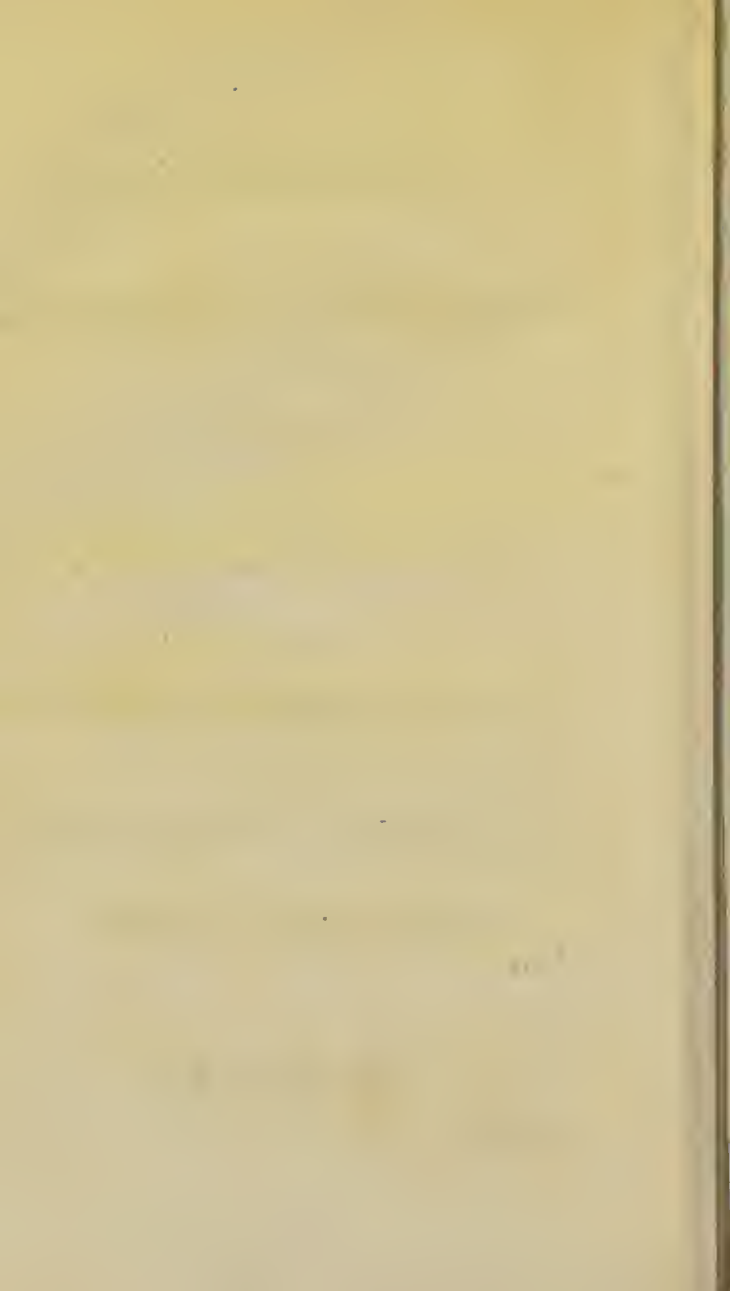
1805.



JOYCE GOLD, PRINTER, SHOE LANE, LONDON.

TO  
MARIA EDGEWORTH,  
AND  
RICHARD LOVELL EDGEWORTH,  
F.R.S. AND M.R.I.A.  
AUTHORS  
OF  
PRACTICAL EDUCATION,  
THE  
THIRD AND FOURTH VOLUMES  
OF  
*SCIENTIFIC DIALOGUES*  
ARE RESPECTFULLY INSCRIBED  
BY  
THE AUTHOR.

JUNE 21, 1802.



## ADVERTISEMENT.

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THE handsome and flattering reception which the former volumes of this work has met with from the public, has afforded the author sufficient encouragement to proceed in the plan which he originally proposed. He trusts that his readers, and particularly those gentlemen and ladies who have introduced the Scientific Dialogues into their schools, will find that the subjects of Hydrostatics and Pneumatics are rendered, in most instances, perfectly familiar to the pupils who have attended to the Con-

versations on Mechanics, to which he has occasionally referred.

Perhaps in that part of the third volume which respects the specific gravities of bodies, the arithmetical operations, though rendered as familiar as the nature of the subject will admit of, may be deemed less easy than the other parts. To those young persons, however, who have studied the subject of decimals, which is by no means a difficult part of arithmetic, no obstacle will present itself, even in the method of obtaining, by experiment and calculation, the specific gravity of any body whatever. In some cases it may be desirable to pass over this part of the book till the reader be a little more grounded in arithmetical operations; but it would have been inexcusable in the author to have omitted it in his plan. The subject

is important, and when understood, it will be found not less interesting than the other parts of the work. Authors in general have not illustrated this branch of Hydrostatics in a manner suited to the apprehension of young persons; and, on that account, it will be found discussed much at large in the Scientific Dialogues.

It is hoped that the explanations of all the Hydrostatic and Pneumatic Engines are perfectly adapted to the understanding of those for whom this course of instruction is intended: that they are, in almost all cases, treated in a manner more familiar than has hitherto been attempted, will not, it is presumed, be denied. The author, in proof of this assertion, might, if he were inclined to mention particular instances, refer to the illustrations of the nature and principles of

the Hydrostatic Paradox in the third volume, and of the Echo and the Steam-engine in the fourth; but he conceives he may confidently appeal to the judgment and decision of those that are accustomed to teach these branches of science, with respect to the *whole* of the two volumes now presented to the public.

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*Speedily will be published,*

BY THE AUTHOR OF THIS WORK,

ELEMENTS OF CHEMISTRY,

Upon the same Plan with the

*SCIENTIFIC DIALOGUES.*

# CONVERSATION I.

---

## INTRODUCTION.

---

FATHER—CHARLES—EMMA.

*FATHER.* In pursuing our course of natural and experimental philosophy, we shall now proceed with that branch of science which is called *Hydrostatics*.

*Emma.* That is a difficult word; what are we to understand by it?

*Father.* Almost all the technical terms made use of in science are either Greek, or derived from the Greek Language. The word *hydro-*

*statics* is formed of two Greek words, which signify *water*, and the science which considers the *weight of bodies*. But hydrostatics, as a branch of natural philosophy, treats of the nature, gravity, pressure, and motion of fluids in general ; and of the methods of weighing solids in them.

*Charles.* Is this an important part of knowledge ?

*Father.* Taken in this extensive sense, it yields to none as to its real importance. And the experiments which I shall shew you are curious and highly amusing.

*Emma.* Shall we be able to repeat them ourselves ?

*Father.* Most of them you will, provided you are very careful in using the instruments, almost all of which are made of glass. I ought

to tell you that many writers divide this subject into two distinct parts, viz. *hydrostatics* and *hydraulics* ; the latter relates particularly to the motion of water through pipes, conduits, &c.

In these conversations, I shall pay no regard to this distinction, but shall, under the general title of *hydrostatics*, describe the properties of all fluids, but principally those of water ; explaining as we go on the motions of it, whether in pipes, pumps, syphons, engines of different kinds, fountains, &c. Do you know what a fluid is ?

*Charles.* I know how to distinguish a fluid from a solid : water and wine are fluids, but why they are so called I cannot tell.

*Father.* A fluid is generally defined as a body, the parts of which readily yield to any impression, and in yielding are easily moved amongst each other.

*Emma.* But this definition does not notice the wetting of other bodies brought into contact with a fluid. If I put my fingers into water or milk, a part of it adheres to them, and they are said to be wet.

*Father.* Every accurate definition must mark the qualities of all the individual things defined by it: now there are many fluids which have not the property of wetting the hand when plunged into them. The air we breathe is a fluid, the parts of which yield to the least pressure, but it does not adhere to the bodies surrounded by it like water.

*Emma.* Air, however, is so different from water, that, in this respect, they will scarcely admit of comparison.

*Charles.* I have sometimes dipped my finger into a cup of quicksilver, but none of the fluid came away with it.

*Father.* You are right; and hence you will find that natural philosophy distinguishes between fluids and liquids. Air, quicksilver, and melted metals, are fluids, but not liquids: while water, milk, beer, wine, oil, spirits, &c. are fluids and liquids.

*Charles.* Are we then to understand, that liquids are known by the property of adhering to different substances which are immersed in them?

*Father.* This description will not always hold ; for though mercury will not stick to your hand if plunged into a cup of it, yet it will adhere to many metals, as tin, gold, &c. And therefore you will remember, that the distinction between liquids and fluids is introduced into books more on account of common convenience, than philosophical accuracy.

*Emma.* You said, I believe, that a fluid is defined as a body, whose parts yield to the smallest force impressed.

*Father.* This is the definition of a perfect fluid ; and the less force that is required to move the parts of a fluid, the more perfect is that fluid.

*Charles.* But how do people reason respecting the particles of which

fluids are composed? have they ever seen them?

*Father.* Philosophers imagine they must be exceedingly small, because with their best glasses they have never been able to discern them. And they contend that these particles must be round and smooth, since they are so easily moved among and over one another. If they are round, you know, there must be vacant spaces left between them.

- *Emma.* - How is that, Papa?

*Father.* Suppose a number of cannon balls were placed in a large tub, or any other vessel, (Plate I. Fig. 1.) so as to fill it up even with the edge: though the vessel would contain no more of these large balls, yet it would hold in the vacant spaces a great many smaller shot; and between these,

others still smaller might be introduced: and when the vessel would contain no more small shot, a great quantity of sand might be shaken in, and, between the pores of which, water or other fluids would readily insinuate themselves.

*Emma.* This I understand; but are there any other proofs that water is made up of such globular particles?

*Father.* There are several:—all aquatic plants, that is, plants which live in water, are said to have their pores round, and are thereby adapted to receive the same shaped particles of water: all mineral and medicinal waters evidently derive their peculiar character from the different substances taken into their pores; from which it has been concluded, that

the particles of water are globular, because such admit of the largest intervals.

Upon this principle tinctures, as those of bark, rhubarb, &c. are made: a quantity of the powder of bark, or any other substance, is put into spirits of wine, the very fine particles are taken into the pores of the spirit: these change the colour of the mass, though it remains as transparent as it was before.

*Charles.* But in these cases, is not the bulk of the fluid increased?

*Father.* In some instances it is, but in others the bulk will remain precisely the same, as the following very easy experiment will shew.

Take a phial with some rain water, mark very accurately the height at which the water stands in the bottle,

after which you may introduce a small quantity of salt, which, when completely dissolved, you will find has not in the least increased the bulk of the water. When the salt is taken up, still sugar may be dissolved in the water without making any addition to its bulk.

*Emma.* Are we then to infer, that the particles of salt are smaller than those of water, and lie between them, as the small shot lie between the cannon balls; and that the particles of sugar are finer than those of salt, and like the sand among the shot, will insinuate themselves into vacuities too small for the admission of the salt?

*Father.* I think the experiment fairly leads to that conclusion. Another fact respecting the particles of

fluids deserving your notice is, that they are exceedingly hard, and almost incapable of compression.

*Charles.* What do you mean, Sir, by compression?

*Father.* I mean the act of squeezing any thing, in order to bring its parts nearer together. Almost all substances with which we are acquainted may, by means of pressure, be reduced into a less space than they naturally occupy. But water, oil, spirits, quicksilver, &c. cannot, by any pressure of which human art or power is capable, be reduced into a space *sensibly* less than they naturally possess.

*Emma.* Has the trial ever been made?

*Father.* Yes, by some of the ablest philosophers that ever lived.

And it has been found, that water will find its way through the pores of gold even, rather than suffer itself to be compressed into a smaller space.

*Charles.* How did that happen?

*Father.* At Florence, a celebrated city in Italy, a globe made of gold was filled with water, and then closed so accurately that none of it could escape. The globe was then put into a press, and a little flattened at the sides : the consequence of which was, that the water came through the fine pores of the golden globe, and stood upon its surface like drops of dew.

*Charles.* Would not the globe then contain as much after its sides were bent in as it did before?

*Father.* It would not ; and as the water forced its way through the gold rather than suffer itself to be brought into a smaller space than it naturally occupied, it was concluded at that time, that water was incompressible. Later experiments have, however, shewn, that those fluids which were esteemed incompressible, are, in a very small degree, as, perhaps, one part in twenty thousand, capable of compression.

*Emma.* Is it on this account you conclude that the particles are very hard ?

*Father.* Undoubtedly ; for if they were not so, you can easily conceive, that since there are vacuities between them as we have shewn, and as are represented in Fig. 1. they must by

very great pressure be brought closer together, and would *evidently* occupy a less space, which is contrary to fact.

NOTE.—Water, oil, spirits, &c. are said to be incompressible, not because they are absolutely so, but because their compressibility is so very small as to make no sensible difference in calculations relative to the several properties of those fluids.

Mr. Canton discovered the compressibility of water in the year 1761, and he says that from repeated trials he found that water will expand, and rise in a tube by removing the weight of the atmosphere, about one part in 21,740, and will be as much compressed under the weight of an additional atmosphere.—*Phil. Trans.* Vol. LII.

## CONVERSATION II.

*Of the Weight and Pressure of Fluids.*

*FATHER.* In our last conversation we considered the nature of the component parts of fluids: I must now tell you, that these parts or particles act, with respect to their weight or pressure, independently of each other.

*Emma.* Will you explain what you mean by this?

*Father.* You recollect, that by the attraction of cohesion\*, the parts of all solid substances are kept together, and press into one common

\* See Vol. I. Of Mechanics. Conver. III,

mass. If I cut a part of this wooden ruler away, the rest will remain in precisely the same situation as it was before. But if I take some water out of the middle of a vessel, the remainder flows instantly into the place from whence that was taken, so as to bring the whole mass to a level.

*Charles.* Have the particles of water no attraction for each other?

*Father.* Yes, in a slight degree. The globules of dew \* on cabbage plants prove, that the particles of water have a greater attraction to one another, than they have to the leaf on which they stand. Nevertheless, this attraction is very small, and you can easily conceive, that if the particles are round, they will

\* See Vol. I. Of Mechanics. Conver. IV.

touch each other in very few parts, and slide with the smallest pressure. Imagine that a few of the little globules were taken out of the vessel, (Fig. 1.) and it is evident that the surrounding ones would fall into their place. It is upon this principle that the surface of every fluid, when at rest, is horizontal or level.

*Charles.* Is it upon this principle that water levels are constructed?

*Father.* It is: the most simple kind of water level is a long wooden trough, which being filled to a certain height with water, its surface shows the level of the place on which it stands.

*Charles.* I did not allude to this kind of levels, but to those smaller ones contained in a glass tube.

*Father.* These are, more properly speaking, air-levels. They are thus constructed: (Plate I. Fig. 2.) *D* is a glass tube fixed into *L*, a socket made generally of brass. The glass is filled with water, or some other fluid, in which is enclosed a single bubble of air. When this bubble fixes itself at the mark *a*, made exactly in the middle of the tube, the place on which the instrument stands is perfectly level. When it is not level, the bubble will rise to the higher end.

*Emma.* What is the use of these levels?

*Father.* They are fixed to a variety of philosophical instruments, such as quadrants, and telescopes for surveying the heavens; and theo-

dilites for taking the level of any part of the earth. They are also useful in the more common occurrences of life. A single instance will show their value: clocks will not keep true time unless they stand very upright; now by means of one of these levels you may easily ascertain whether the bracket, upon which the clock in the passage stands, is level.

*Emma.* But I remember when Mr. F—— brought home your clock, he tried if the bracket was even by means of one of Charles's marbles. How did he know by this?

*Father.* The marble, being round, touched the board in a point only, consequently the line of direction\* could not fall through that point,

\* See Vol. I. Of Mechanics. Conver. IX.

but the marble would roll, unless the bracket was very level; therefore, when the marble was placed in two or more different parts of the board, and did not move to one side or the other, he might safely conclude that it was level.

*Charles.* Then the water-level and the rolling of the marble depend on the same principle.

*Father.* They do, upon the supposition that the particles of water are round. The water-level will, however, be the most accurate, because we may imagine, that the parts of which water is composed are perfectly round, and, therefore, as may be geometrically proved, they will touch only in an infinitely small point; whereas, marbles made by

human contrivance, touch in many such points.

We now come to another very curious principle in this branch of science, viz. *that fluids press equally in all directions*. All bodies, both fluid and solid, press downwards by the force of gravitation, but fluids of all kinds exert a pressure upwards and sideways equal to their pressure downwards.

*Emma.* Can you shew any experiments in proof of this?

*Father.* A, B, C, (Plate I. Fig. 3.) is a bended glass tube: with a small glass funnel (Plate I. Fig. 4.) pour in the mouth A a quantity of sand. You will find that, when the bottom part is filled, whatever is poured in afterwards will stand in the side of the tube A B, and not rise in the other side B C.

*Charles.* The reason of this is, that by the attraction of gravitation all bodies have a tendency to the earth\*; that is, in this case, to the lowest part of the tube; but if the sand ascended in the side B C, its motion would be directly the reverse of this principle.

*Father.* You mean to say that the pressure would be upwards, or *from* the center of the earth.

*Charles.* It certainly would.

*Father.* Well, we will pour away the sand, and put water in its place: what do you say to this?

*Emma.* The water is level in both sides of the tube.

*Father.* This then proves, that with respect to fluids there is a pres-

\* See Vol. I. Of Mechanics. Conver. V.

sure upwards at the point B as well as downwards. I will shew you another experiment.

A B (Plate I. Fig. 5.) is a large tube or jar having a flat bottom: *a b* is a smaller tube open at both ends. While I fill the jar with water, I take care to hold the small tube so close to the bottom of the jar as to prevent any water from getting into the tube. I then raise it a little, and you see it is instantly filled with water from the jar.

*Charles.* It is: and the water is level in the jar and the tube.

*Father.* The latter, you saw, was filled by means of the pressure upwards, contrary to its natural gravity.

Take out the tube; now the water having escaped, it is filled with air.

Stop the upper end *a* with a cork, and plunge it into the jar, the water will only rise as high as *b*.

*Emma.* What is the reason of this, Papa?

*Father.* The air with which the tube was filled is a body, and unless the water were first to force it out from the tube, it cannot take its place. While this ink-stand remains here, you are not able to put any other thing in the same part of space.

*Charles.* If air be a substance, and the tube is filled with it, how can any water make its way into the tube?

*Father.* This is a very proper question. Air, though a substance, and, as we have already observed, a fluid too, differs from water in this

respect, that it is easily compressible; that is, the air, which by the natural pressure of the surrounding atmosphere, fills the tube, may, by the additional upward pressure of the water, be reduced into a smaller space, as *a b*. Another experiment will illustrate the difference between compressible and incompressible fluids.

Fill the tube, which has still a cork in one end, with some coloured liquor, as spirits of wine; over the other end place a piece of pasteboard, held close to the tube, to prevent any of the liquor from escaping: in this way introduce the tube into a vessel of water, keeping it perpendicular all the time: you may now take away the pasteboard, and force the tube to any depth, but the spirit is not like the air, it cannot in this

manner be reduced into a space smaller than it originally occupied.

*Emma.* Why did not the spirits of wine run out of the tube into the water?

*Father.* Because spirits are lighter than water, and it is a general principle that the lighter fluid always ascends to the top.

Take a thin piece of horn or pasteboard, and while you hold it by the edges, let your brother put a pound weight upon it: what is the result?

*Emma.* It is almost bent out of my hand.

*Father.* Introduce it now into a vessel of water at the depth of twelve or fifteen inches, and bring it parallel to the surface. In this position, it sustains many pounds weight of water.

*Charles.* Nevertheless it is not bent in the least.

*Father.* Because the upward pressure against the lower surface of the horn is exactly equal to the pressure downward, or, which is the same thing, it is equal to the weight of the water which it sustains on the upper surface.

You may vary these experiments by yourselves till we meet again: when we shall resume the same subject.

## CONVERSATION III.

*Of the Weight and Pressure of Fluids.*

**CHARLES.** When you were explaining the principle of the Wheel and Axis\*, I asked the reason why, as the bucket ascended near the top of the well, the difficulty in raising it increased? I have just now found another part of the subject beyond my comprehension. After the bucket is filled with water, it sinks to the bottom of the well, or as far as the rope will suffer it; but in drawing it

\* See Vol. I. Of Mechanics. Conver. XVII.

up through the water, it seems to have little or no weight till it has ascended to the surface of the water. How is this accounted for?

*Father.* I do not wonder that you have noticed this circumstance as singular. It was long believed by the antients that water did not gravitate, or had no weight in water: or, as they used to express it more generally, that fluids do not gravitate *in proprio loco*.

*Emma.* I do not understand the meaning of these hard words.

*Father.* Nor would I have made use of them, only that you can scarcely open a treatise on this subject without finding the phrase. I will explain their meaning without translating the words, because a mere translation would give you a very inadequate

idea of what the writers intended to express by them.

No one ever doubted that water and other fluids had weight when considered by themselves; but it was supposed that they had no weight when immersed in a fluid of the same kind. The fact which your brother has just mentioned, respecting the bucket was the grand argument upon which they advanced and maintained this doctrine.

*Emma.* Does it not weigh any thing, then, till it is drawn above the surface?

*Father.* You must, my little girl, have patience, and you shall see how it is. Here is a glass bottle A, (Plate I. Fig. 6.) with a stop-cock B cemented to it, by means of which the air may be exhausted from the

bottle, and prevented from returning into it again. The whole is made sufficiently heavy to sink in the vessel of water c d.

The bottle must be weighed in air, that is, in the common method; and suppose it weighs 12 ounces, let it now be put into the situation which is represented by the figure, when the weight of the bottle must be again taken by putting weights into the scale z. I then open the stop-cock while it is under water, and the water immediately rushes in and fills the bottle, which overpowers the weights in the scale. I now put other weights, say 8 ounces, into the scale, to restore the equilibrium between the bottle and scale. It is evident, then, that 8 ounces is the weight of the water in the bottle,

while weighed under water. Fasten the cock, and weigh the bottle in the usual way in the air.

*Charles.* It weighs something more than 20 ounces.

*Father.* That is 12 ounces for the bottle, and 8 ounces for the water, besides a small allowance to be made for the drops of water that adhere to the outside of the bottle. Does not this experiment prove that the water in the bottle weighed just as much in the jar of water as it weighed in the air?

*Emma.* I think it does.

*Father.* Then we are justified in concluding that the water in the bucket, which the bottle may represent, weighed as much while under water in the well, as it did after it was raised above the surface.

*Charles.* This fact seems decisive, but the difficulty still remains in my mind, for the weight of the bucket is not felt till it is rising above the surface of the water.

*Father.* It may be thus accounted for: any substance of the same specific gravity with water, may be plunged into it, and it will remain wherever it is placed, either near the bottom, in the middle, or towards the top, consequently it may be moved in any direction with the application of a very small force.

*Emma.* What do you mean by the specific gravity of a body?

*Father.* The *specific gravity* of any body is its weight *compared* with that of any other body. Hence it is also called the *comparative gravity*: thus if a cubical inch of water be

equal in weight to a cubical inch of any particular kind of wood, the specific or comparative gravities of the water and that wood are equal. But since a cubical inch of deal is lighter than a cubical inch of water, and that is lighter than the same bulk of lead or brass, we say the specific gravity of the lead, or brass, is greater than that of water, and the specific gravity of water is greater than that of deal.

*Charles.* The water in the bucket must be of the same specific gravity with that in the well, because it is a part of it.

*Father.* And the wooden bucket differs very little in this respect from the water ; because, though the wood is lighter, yet the iron of which the hoops and handle are composed is

specifically heavier than water ; so that the bucket and water are nearly of the same specific gravity with the water in the well, and therefore it is moved very easily through it.

Again, we have already proved that the upward pressure of fluids is equal to the pressure downwards, therefore the pressure at the bottom of the bucket upwards being precisely equal to the same force in a contrary direction, the application of a very small force, in addition to the upward pressure, will cause the bucket to ascend.

*Emma.* You account for the easy ascent of the bucket upon the same principle by which you have shewn that horn or pasteboard will not be

bent, when placed horizontally at any depth in water?

*Father.* Yes, I do : and I will shew you some other experiments to prove the effect of the upward pressure.

Take a glass tube, open at both ends, the diameter of which is about the eighth of an inch, fill it with water, and close the top with your thumb; you may now take it out of the water, but it will not empty itself so long as the top is kept closed.

*Charles.* This is not the upward pressure of water, because the tube was taken out of it.

*Father.* You are right : it is the upward pressure of the air, which, while the thumb is kept on the top, is not counterbalanced by any down-

ward pressure, therefore it keeps the water suspended in the tube.

Take this ale-glass, fill it with water, and cover it with a piece of writing-paper: then place your hand evenly over the paper, so as to hold it very tight about the edge of the glass, which you may now invert, and take away your hand without any danger of the water falling out.

*Emma.* Is the water sustained by the upward pressure of the air?

*Father.* The upward pressure of the air against the paper sustains the weight of water, and prevents it from falling.

You have seen the instrument used for tasting of beer or wine.

*Emma.* Yes; it is a tin tube that holds about half a pint, into which

very small tubes are inserted at the top and bottom.

*Father.* The longer one is put into the hole made for the vent-peg, and then the beer or wine is, by drawing out the air from it, forced into the large part of the tube, and by putting the thumb or finger on the upper part, the whole instrument may be taken out of the cask, and removed any where, for the pressure of the air against the bottom surface of the lower tube keeps the liquor from running out ; but the moment the thumb is taken from the top, the liquor descends by the downward pressure of the air.

*Charles.* Is it for a similar reason that vent-holes are made in casks ?

*Father.* It is : for when a cask is

full, and perfectly close, there is no downward pressure, and therefore the air pressing against the mouth of the cock keeps the liquor from running out; a hole made at the top of the cask admits the external pressure of the air, by which the liquor is forced out. In large casks of ale or porter, where the demand is not very great, the vent-hole need seldom be used, for a certain portion of the air contained in the liquor escapes, and being lighter than the beer, ascends to the top, by which a pressure is created without the assistance of the external air.

CONVERSATION IV.

---

*Of the lateral Pressure of Fluids.*

*FATHER.* It is time now to advance another step in this science, and to shew you that the *lateral*, or *side* pressure, is equal to the perpendicular pressure.

*Emma.* If the upward pressure is equal to the downward, and the side pressure is also equal to it, then the pressure is equal in all directions.

*Father.* You are right. Though the side direction may be varied in many ways, yet there are only the upward, downward, and lateral di-

rections. The two former we have shewn are equal. That the side pressure is equal to the perpendicular pressure downwards, is demonstrated by a very easy experiment.

A B (Plate 1. Fig. 7.) is a vessel filled with water, having two equal orifices or holes, *a*, *b*, bored with the same tool, one at the side, and the other in the bottom: if these holes are opened at the same instant, and the water suffered to run into two glasses, it will be found that, at the end of a given time, they will have discharged equal quantities of water; which is a clear proof that the water presses side-wise as forcibly as it does downwards.

*Charles.* Are we then to take it as a general principle that fluids press in every possible direction?

*Father.* This, I think, our experiments have proved: but you must not forget that it is only true upon the supposition that *the perpendicular heights are equal*. For in the last experiment, if the hole *b* had been bored an inch or two higher in the side of the vessel, as at *c*, the quantity of water running out at *a* would have been greater than that at *b*, and much greater would it have been, if the hole had been bored at four or five inches above the bottom of the vessel.

This subject of pressure may be farther illustrated. At the bottom of this tube *z y*, (Plate I. Fig. 8.) open at both ends, I have tied a piece of bladder, and have poured in water till it stands at the mark *x*. Owing to the pressure of the water, the blad-

der is convex, that is, bent outwards; dip it into the jar, (Fig. 5.) the bladder is still convex: thrust it gently down, the surface of the water in the tube is now even with that in the jar.

*Emma.* It is; and the bladder at the bottom is become flat.

*Father.* The perpendicular depths being equal, the pressure upward is equal to that downwards, and the water in the tube is exactly balanced by the water in the jar. Let the tube be thrust deeper into the water.

*Charles.* Now the bladder is bent upwards.

*Father.* The upward pressure is estimated by the perpendicular depth of the water in the jar, measured from the surface to the bottom of the tube; but the pressure downwards must be

estimated by the perpendicular height of the water in the tube, which being less than the former, the pressure upward in the same proportion overcomes that downwards, and forces up the bladder into the position as you see it. This and the following experiment are some of the best that can be exhibited in proof of the upward pressure of fluids.

Dip an open end of a tube, having a very narrow bore, into a vessel of quicksilver; then stopping the upper orifice with the finger, lift up the tube out of the vessel, and you will see a sort of column of quicksilver hanging at the lower end, which, when dipped in water lower than 14 times its own length, will, upon removing the finger, be pressed upwards into the tube.

*Emma.* Why do you fix upon 14 times the depth?

*Father.* Because quicksilver is 14 times heavier than water. Upon this principle of the upward pressure, lead or any other metal may be made to swim in water.  $A B$  (Plate I. Fig. 9.) is a vessel of water, and  $a b$  is a glass tube open throughout,  $d$  is a string by which a flat piece of lead  $x$  may be held fast to the bottom of the tube. To prevent the water from getting in between the lead and the glass, a piece of wet leather is first put over the lead.

In this situation, let the tube be immersed in the vessel of water, and if it be plunged to the depth of about eleven times the thickness of the lead before the string be let go, the lead will not fall from the tube, but be

kept adhering to it by the upward pressure below it.

*Emma.* Is lead 11 times heavier than water?

*Father.* It is between 11 and 12 times heavier; and therefore to make the experiment sure, the tube should be plunged somewhat deeper than 11 times the thickness of the lead.

*Charles.* Is it not owing to the wet leather that the lead sticks to the tube, rather than to the upward pressure?

*Father.* If that be the case, it will remain fixed if I draw up the tube an inch or two higher:—I will try it.

*Emma.* It has fallen off.

*Father.* Because when the tube was raised, the upward pressure was diminished so much as to become too

small to balance the weight of the lead. But if the adhering together of the lead and tube had been caused by the leather, there would be no reason why it should not operate the same at six or nine times the depth of the lead's thickness as well as at 11 or 12 times that thickness.

This last experiment is neatly described by Mr. Capel Lofft in the following lines :

————— And since on every side  
 The fluid presses with an equal force  
 Proportion'd to the column of its height,  
 The yielding water may be made to buoy  
 Or *lead* or *gold*, if, artfully, so much  
 Be made to float above the weight immers'd,  
 As, in proportion to the mass entire,  
 Equals the difference of gravity  
 Between the *fluid* and the *solid* mass.

EUDOSIA.

CONVERSATION V.

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*Of the Hydrostatical Paradox.*

*EMMA.* You are to explain a paradox to-day : I thought natural philosophy had excluded all paradoxes.

*Father.* Dr. Johnson has given this definition of a paradox, “ an assertion contrary to appearances :” now the assertion which I am to refer you to is, *that any quantity of water, however small, may be made to balance and support any quantity, however large.* That a pound of water, for instance, should, without any

mechanical advantage, be made to support ten pounds, or a hundred, or even a ton weight, seems at first incredible; certainly it is contrary to what one should expect, and on that account the experiment to shew this fact has usually been called the hydrostatical paradox.

*Charles.* It does appear unaccountable: I hope the experiments may be very easy to be understood.

*Father.* Many have been invented for the purpose, but I know of none better than those described by Mr. Ferguson in his lectures on select subjects.

O B G H (Plate II. Fig. 10.) is a glass vessel, consisting of two tubes of very different sizes, joined together, and freely communicating with one another. Let water be poured

in at H, which will pass through the joining of the tubes, and rise in the wide one to the same height exactly as it stands in the smaller; which shows that the small column of water in D G balances the large one in the other tube. This will be the case if the quantity of water in the small tube be a thousand or a million of times less than the quantity in the larger one.

If the smaller tube be bent in any oblique situation, as G F, the water will stand at F, that is, on the same level as it stands at A. This would be the case, if instead of two tubes there were any given number of them connected together at B, and varied in all kinds of oblique directions, the water would be on a level in them all; that is, the *perpendicu-*

*lar height* of the water would be the same.

*Charles.* This does not quite satisfy me ; because it appears that a great part of the water in the large tube is supported by the parts *B* about the bottom, and therefore that the water in the smaller tube only sustains the pressure of a column of water, the diameter of which is equal to its own diameter.

*Father.* This would be the case if the pressure of fluids were only downwards, but we have shewn that it acts in all directions : and therefore the pressure of the parts near the side of the tube acts against the column in the middle, which you suppose is the only part of the water sustained by that which is contained in the small tube, consequently the smaller

quantity of water in  $DB$  sustains the larger one in  $AB$ .

Let us try another experiment.

$AB$  and  $ab$  (Plate II. Figs. 11 and 12.) are two vessels, having their bottoms  $pd$  and  $pd$  exactly equal, but the contents of one vessel is 20 times greater than the other; that is, Fig. 11, when filled up to  $A$ , will hold but one pint of water, whereas Fig. 12, when filled to the same height, will hold 20 pints. Brass bottoms,  $cc$ , are fitted exactly to each vessel, and made water tight by pieces of wet leather. Each bottom is joined to its vessel by a hinge  $p$ , so that it opens downwards, like the lid of a box. By means of a little hook  $d$ , a pulley  $F$ , and a weight  $E$ , the bottom is kept close to the vessel,

and will hold a certain quantity of water.

*Emma.* That is, till the *weight* of the water overcome the weight *E*.

*Father.* I should rather say, till the *pressure* of the water overcome the weight *E*.

Now hold the vessel (Fig. 12.) upright in your hands, while I gradually pour water into it with a funnel; the pressure bears down the bottom, and, of course, raises the weight, and a small quantity of the water escapes. Let us mark the height *H A*, at which the surface of the water stood in the vessel when the bottom began to give way.

Try the other vessel (Fig. 11.) in the same manner, and we shall see that when the water rises to *A*, that is, to just the same height in this

vessel as in the former, the bottom will also give way, as it did in the other case. Thus equal weights are overcome in the one case by 20 pints of water, and in the other by a single pint. The same would hold good if the difference were greater or less in any given proportion.

*Emma.* What is the reason of this, Papa?

*Father.* It depends upon two principles with which you are acquainted. The first is, that fluids press equally in all directions: and the second is, that action and re-action are equal and contrary to each other\*. The water, therefore, below the fixed part  $B g f$  will press as much upward against the inner surface, by the ac-

\* See Vol. I. Of Mechanics. Conver. XI.

tion of the small column  $A g$ , as it would by a column of the *same height*, and of any other diameter whatsoever : and since action and re-action are equal and contrary, the action against the inner surface  $B g f$  will cause an equal re-action of the water in the cavity  $B f c c$  against the bottom  $c c$ , consequently the pressure upon  $c c$ , Fig. 11. will be as great as it was upon the same part of Fig. 12.

*Charles.* Can you prove by experiment that there is this upward pressure against the inner surface  $B g f$  ?

*Father.* Very easily : suppose at  $f$  there were a little cork, to which a small string was fixed : I might place a tube over the cork, and then draw it out, the consequence of which would be, that the water in the vessel

would force itself into the tube, and stand as high in it as it does in the vessel. Would not this experiment prove that there was this upward pressure against  $B g f$ ?

*Charles.* It would: and I can easily conceive, that if other tubes were placed in the same manner, in different parts of  $B g f$ , the same effect would be produced.

*Father.* Then you must admit, that the action against  $B g f$ , or, which is the same thing, the re-action against  $C C$ , that is, the pressure of the water against the bottom, is equally great as it would be if the vessel were as large in every part as it is at the bottom, and the water stood level to the height  $A A$ .

*Charles.* Yes, I do: because if tubes were placed in every part of

*E.f.*, the same effect would be produced in them all, as in the single one at *f*; but if the whole surface were covered with small tubes, there would then be little or no difference between the two vessels, (Figs. 11 and 12.)

*Father.* There would be no difference, provided you kept filling the large tube, so that the water should stand in them all at the same level *A A*. Otherwise, the introduction of a single tube *af* would make a material difference: for though the water in *AC* would overcome the weight *E*, yet if with my hand I prevent any of the water from running out till I have taken out the cork, and suffered the water to force itself out of the vessel into the small tube, I may remove my hand with

safety, for the water will not overcome the weight now, though there is certainly the same quantity of water in it as there was before the little tube  $af$  was inserted.

*Emma.* I think I see the reason of this: the water stood as high as  $Aa$  before the little tube was introduced, but now it stands at the level  $xx$ , and you told us yesterday that the pressures were only equal, provided the *perpendicular heights were also equal*.

*Father.* I am glad to find you so attentive to what I say. In order that the pressure may overcome the weight  $E$ , you must put in more water till it rise to the level  $AA$ , and now you see the weight rises, and the water flows out.

I will put another tube at  $g$ , and the water rushing into that causes the level to descend again to  $x x$ , and I must put more water in to bring the level up to  $A a$ , before it can overcome the weight  $E$ . What I have shewn in these two cases will hold true in all, supposing you fill the cover with tubes.

*Charles.* I see, then, that it is the difference of the perpendicular heights which causes the difference of pressure, and can now fully comprehend the reason why a pint of water may be made to balance or support a hogshead: or, in the words with which you set out, that any *quantity of water, however small, may be made to balance and support any other quantity however large.*

*Father.* It is to this principle in hydrostatics that Mr. Capel Lofft refers in his work entitled “Eudosia, or a Poem on the Universe:”

All *homogeneous* fluids, which ascend  
To equal heights, and join in equal base,  
Balance each other; howsoe’er in form  
Of the containing vessel disagreed,  
Or in the fluid quantity contain’d.

*Emma.* What does he mean by the word *homogeneous*?

*Father.* Homogeneous fluids, are fluids of the *same kind*. What has been proved with regard to water may be shewn to hold with regard to wine, or oil, or any other fluid. But the experiment will not answer if different fluids are made use of, as water and oil together.

## CONVERSATION VI.

*Of the Hydrostatic Bellows.*

*FATHER.* I think we have made it sufficiently clear that the pressure of fluids *of the same kind* is always proportional to the area of the base multiplied into the perpendicular height at which the fluid stands, without any regard to the form of the vessel, or the quantity of fluid contained in it.

*Emma.* I cannot help saying, that it still appears very mysterious to me, that a pint of water (Fig. 11.) should have an equal pressure with

the 20 pints in the next vessel. You will not say that one pint weighs as much as the 20?

*Father.* Your objection is proper. The pressure of the water upon the bottom c c, does not in the least alter the weight of the vessel and water considered as one mass; for the action and reaction, which cause the *pressure*, destroy one another with respect to the *weight* of the vessel, which is as much sustained by the action upwards as it is pressed by the reaction downwards.

The *pressure* of water and other fluids differs from the gravity or *weight* in this respect; the *weight* is according to the *quantity*; but the *pressure* is according to the *perpendicular height*.

*Charles.* Suppose both vessels were

filled with any solid substance, would the effect produced be very different?

*Father.* If the water were changed into ice, for instance, the pressure upon the bottom of the smaller vessel would be much less than that upon the larger.

Here is another instrument (Fig. 13.) to shew you that a very few ounces of water will lift up and sustain a large weight.

*Emma.* What is the instrument called?

*Father.* It is made like common bellows, only without valves, and writers have given it the name of the hydrostatic bellows. This small tin-pipe *c o* communicates with the inside of the bellows. At present the upper and lower board are kept close to one another with the weight

w. The inside of the boards are not very smooth, so that water may insinuate itself between them: pour this half pint of water into the tube.

*Charles.* It has separated the boards, and lifted up the weight.

*Father.* Thus you see that seven or eight ounces of water has raised and continues to sustain a weight of 56lb. By diminishing the bore of the pipe, and increasing its length, the same or even a smaller quantity of water would raise a much larger weight.

*Charles.* How do you find the weight that can be raised by this small quantity of water?

*Father.* Fill the bellows with water, the boards of which, when distended, are three inches asunder: I will screw in the pipe. As there is no pressure

upon the bellows, the water stands in the pipe at the same level with that in the bellows at  $z$ .

Now place weights on the upper board till the water ascend exactly to the top of the pipe  $e$ : these weights express the weight of a pillar or column of water, the base of which is equal to the area of the lower board of the bellows, and the height equal to the distance of that board from the top of the pipe.

*Emma.* Will you make the experiment?

*Father.* Your brother shall first make the calculation.

*Charles.* But I must look to you for assistance.

*Father.* You will require very little of my help. Measure the diameter of the bellows, and the per-

pendicular height of the pipe from the bottom board.

*Charles.* The bellows are circular, and 12 inches in diameter; the height of the pipe is 36 inches.

*Father.* Well; you have to find the solid contents of a cylinder of these dimensions; that is, the area of the base multiplied by the height.

*Charles.* To find the area I multiply the square of 12 inches, that is 144, by the decimals .7854, and the product is 113, the number of square inches in the area of the bottom board of the bellows. And 113 multiplied by 36 inches, the length of the pipe, gives 4068, the number of cubic inches in such a cylinder; this divided by 1728 (the number of cubic inches in a cubic foot), leaves a quotient of 2.3 cubic feet, the solid

contents of the cylinder. Still I have not the weight of the water.

*Father.* The weight of pure water is equal in all parts of the known world, and a cubical foot of it weighs 1000 ounces.

*Charles.* Then such a cylinder of water as we have been conversing about weighs 2300 ounces, or 144 pounds nearly.

*Emma.* Let us now see if the experiment answers to Charles's calculation.

*Father.* Put the weights on carefully, or you will dash the water out at the top of the pipe, and I dare say that you will find the fact agrees with the theory.

*Charles.* If instead of this pipe, one double the length was used,

would the water sustain a double weight?

*Father.* It would: and a pipe three or four times the length would sustain three or four times greater weights.

*Charles.* Is there then no limits to this kind of experiment except those which arise from the difficulty of acquiring length in the pipe?

*Father.* The bursting of the bellows would soon determine the limit of the experiment. Dr. Goldsmith says that he once saw a strong hogs-head split by this means. A strong small tube made of tin, about 20 feet long, was cemented into the bung-hole, and then water was poured in to fill the cask: when it was full, and the water had risen to within about

a foot of the top of the tube, the vessel burst with prodigious force.

*Emma.* It is very difficult to conceive how this pressure acts with such power.

*Father.* The water at  $o$  is pressed with a force proportional to the perpendicular altitude  $eo$ ; this pressure is communicated horizontally in the direction  $opq$ , and the pressure so communicated acts, as you know, equally in all directions: the pressure therefore downwards upon the bottom of the bellows is just the same as it would be if  $pqr$  were a cylinder of water.

The experiment made on the bellows might, for want of such an instrument, be made by means of a bladder in a box with a moveable lid,

*Emma.* Has this property of hydrostatics been applied to any practical purposes?

*Father.* The knowledge of it is of vast importance in the concerns of life. On this principle a press of immense power has been formed (Plate II. Fig. 14.) which we shall describe after you are acquainted with the nature and structure of valves, and which is used in almost all sea-port towns for pressing into small compass hay and other commodities which it is necessary to transport on board of Ship, but which in their natural state would take up too much space.

CONVERSATION VII.

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*Of the Pressure of Fluids against the  
Sides of Vessels.*

*FATHER.* Do you recollect, Charles, the law by which you calculate the accelerated velocity of falling bodies \*?

*Charles.* Yes: the velocity increases in the same proportion as the odd numbers 1, 3, 5, 7, 9, &c.; that is, if at the end of one second of time it has carried the body through 16 feet; then in the next second the

\* See Vol. I. Of Mechanics. Conver. VII. and VIII.

body will descend three times 16, or 48 feet: in the third it will descend five times 16 feet, and in the next seven times 16 feet, and so on continually increasing in the same proportion.

*Father.* How many feet has it fallen altogether at the end of the *third* second?

*Emma.* I recollect this very well; the whole space through which it will fall in three seconds is nine times 16, or 144 feet; because the rule is, that the whole spaces described by falling bodies are in proportion to the squares of the times, and the square of three is nine, therefore if it fall through 16 feet in the first second, it will in three seconds fall through nine times 16, and in five or eight seconds it will descend in the

former case through 25 times 16 feet, and in the latter through 64 times 16 feet, for 25 is the square of five, and 64 is the square of eight. The example of the arrow which you gave me to work has fixed the rule in my mind.

*Father.* Well, then, what I am going to tell you, will tend to impress the rule still stronger in your memory.

The pressure of fluids against the sides of any vessel increases in the same proportion, and is governed by the same laws.

Suppose  $a b c d$  (Plate II. Fig. 15.) to be a cubical vessel filled with water, or any other fluid, and one of the sides to be accurately divided into any number of equal parts by the lines 1, 7; 2, 8; 3, 9, &c.

Now if the pressure of the water upon the part of the vessel *a* 1 *b* 7 be equal to an ounce or a pound, then the pressure upon the part 1 2 7 8 will be equal to three ounces or three pounds; and the pressure upon the part 2 3 8 9 will be equal to five ounces or pounds, and so on.

*Charles.* Then I see the reason why the other part of the rule holds true; viz. that the pressure against the whole side must vary as the square of the depth of the vessel.

*Father.* Explain to us the reason.

*Charles.* The pressure upon the *first* part being 1, and that upon the *second* 3, and that upon the *third* 5; then the pressure upon the first and second taken together is by addition 4: upon the first, second, and third, it must be 9; and upon the first, se-

cond, third, and fourth, it will be 16; but 4, 9, 16, are the squares of 2, 3, 4.

*Emma.* And the pressure upon the whole side  $a b c d$  must be 36 times greater than that upon the small part  $a 1 b 7$ .

*Charles.* And if there are three vessels, for instance, whose depths are as 1, 2, and 3, the pressure against the side of the second will be four times greater than that against the first; and the pressure against the side of the third will be nine times greater than that against the first.

*Father.* The beautiful simplicity of the rule, and its being the same by which the accelerating velocity of falling bodies is governed, will make it impossible that you should hereafter forget it.

The use that I shall hereafter call you to make of the rule induces me to put a question to Emma.

In two canals, one five feet deep, and the other 15, what difference of pressure will there be against the sides of these canals?

*Emma.* The pressure against the one will be as the square of 5, or 25; that against the other will be as the square of 15, or 225; now the latter number divided by the former gives 9 as a quotient, which shews that the pressure against the sides of the deep canal is nine times greater than that against the sides of the shallow one.

Can this principle be proved by an experiment?

*Father.* By a very simple one: (Plate II. Fig. 16.) is a vessel of the

same size as the last, the bottom and side *b* are wood mortised together; the front and opposite side are glass carefully inserted in the wooden parts, and made water tight. A thin board *c* hangs by two hinges *x y*, and is held close to the glass panes by means of the pulley and weight *w*. The board is covered with cloth and made water tight.

Now observe the exact weight which is overcome when the water is poured in and rises to the line 1; then hang on four times that weight, and you will see that water may be poured into the vessel till it rise to the line 2, when the side *c* will give way and let part of it out.

*Emma.* But why does only a part run away?

*Father.* Because when a small quantity of the water has escaped, the weight  $w$  is greater than the pressure of the water against  $c$ , and therefore the door  $c$  will be drawn close to the glass panes, and confine the rest within the vessel.

You may now hang on a weight nine times greater than the first, and then the vessel will contain water till it rise up to the mark 3, when the side will give way by the pressure and part of the water escape.

*Charles.* You have explained the manner of estimating the pressure of fluids against the sides of a vessel; by what rule are we to find the pressure upon the bottom?

*Father.* In such vessels as those which we have just described; that is, where the sides are perpendicular to

the bottom, and the bottom parallel to the horizon, *the pressure will be equal to the weight of the fluid.*

*Emma.* If then the vessel *y z* hold a gallon of water, which weighs about eight pounds. and if the bottom were made movable like the side, would a weight of eight pounds keep the water in the vessel?

*Father.* It would: for then there would be an equilibrium between the pressure of the water and the weight. And the pressure upon any one side is equal to half the pressure upon the bottom; that is, provided the bottom and sides are equal to one another

*Charles.* Pray, Sir, explain how this is made out.

*Father.* The pressure upon the bottom is, as we have shewn, equal

to the weight of the fluid. But we have also shewn that the pressure on the side grows less and less continually, till at the surface it is nothing. Since then the pressure upon the bottom is truly represented by the area of the base multiplied into the altitude of the vessel; the pressure upon the side will be represented by the base multiplied into half the altitude.

*Emma.* Is the pressure upon the four sides equal to twice the pressure upon the bottom?

*Father.* It is: consequently the pressure of any fluid upon the bottom and four sides of a cubical vessel is equal to three times the weight of the fluid.

Can you, Charles, tell me the difference between the *weight* and the

*pressure* of a conical vessel of water standing on its base?

*Charles.* The *weight* of a conical vessel of any fluid is found by multiplying the area of the base by *one third part* of its perpendicular height \* : but the *pressure* is found by multiplying the base by the whole perpendicular height; therefore the pressure upon the base will be equal to three times the weight.

NOTE.—The rule for finding the solidity of a cone or a pyramid is this, “multiply the area of the base by  $\frac{1}{3}$  of the height, and the product will be the solidity.”

\* See Bonnycastle's Introduction to Mensuration, &c. p. 132. Second Edition.

## CONVERSATION VIII.

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*Of the Motion of Fluids.*

*FATHER.* We will now consider the pressure of fluids with regard to the motion of them through spouting-pipes, which is subject to the same law.

If the pipes at 1 and 4 (Fig. 15.) be equal in size and length, the discharge of water by the pipe at 4 will be double that at 1. Because the velocity with which water spouts out at a hole in the side or bottom of a vessel, is as the *square-root* of the

distance of the hole below the surface of the water.

*Emma.* What do you mean by the square-root?

*Father.* The square-root of any number is that which being multiplied into itself produces the said number. Thus the square-root of 1 is 1; but of 4 it is 2; of nine it is 3; and of 16 it is 4, and so on.

*Charles.* Then if you had a tall vessel of water with a cock inserted within a foot of the top, and you wished to draw the liquid off three times faster than it could be done with that, what would you do?

*Father.* I might take another cock of the same size, and insert it into the barrel at nine feet distance from the surface, and the thing required would be done.

*Emma.* Is this the reason why the water runs so slowly out of the cistern when it is nearly empty in comparison of what it does when the cistern is just full?

*Father.* It is: because the more water there is in the cistern, the greater the pressure upon the part where the cock is inserted; and the greater the pressure, the greater the velocity, and consequently the quantity of water that is drawn off in the same time.

In some large barrels there are two holes for cocks, the one about the middle of the cask, the other at the bottom; now if when the vessel is full you draw the beer or wine from both cocks at once, you will find that the lower one gives out the liquor much the fastest.

*Charles.* In what proportion?

*Father.* As the square-root of 2 is greater than that of 1; that is, while you had a quart from the upper cock, three pints nearly would run from the lower one.

*Emma.* Are we then to understand, that the *pressure* against the side of a vessel increases in proportion to the *square* of the depth; but the *velocity of a spouting pipe*, which depends upon the pressure, increases only as the *square root* of the depth?

*Father.* That is the proper distinction.

*Charles.* Is not the velocity of water running out of a vessel that empties itself continually decreasing?

*Father.* Certainly: because in proportion to the quantity drawn off, the surface descends, and conse-

quently the perpendicular depths become less and less.

The spaces described by the descending surface, in equal portions of time, are as the odd numbers 1, 3, 5, 7, 9, &c. taken backwards.

*Emma.* If the height of a vessel filled with any fluid be divided into 25 parts, and in a given space of time, as a minute, the surface descend through nine of those parts, will it in the next minute descend through seven of those parts, and the third minute five, in the fourth three, and in the fifth one?

*Father.* This is the law, and from it have been invented *clepsydras* or water clocks.

*Charles.* How are they constructed, Sir?

*Father.* Take a cylindrical vessel,

and having ascertained the time it will require to empty itself, then divide, by lines, the surface into portions which are to one another as the odd numbers 1, 3, 5, 7, &c.

*Emma.* Suppose the vessel require six hours to empty itself, how must it be divided?

*Father.* It must be first divided into 36 equal parts; then, beginning from the surface, take 11 of those parts for the first hour, nine for the second, seven for the third, five for the fourth, three for the fifth, and one for the sixth: and you will find that the surface of the water will descend regularly through each of these divisions in an hour.

I believe both of you have seen the locks that are constructed on the river Lea.

*Charles.* Yes: and I have wondered why the flood-gates were made of such an enormous thickness.

*Father.* But after what you have heard respecting the pressure of fluids, you will see the necessity that there is for the great strength employed.

*Charles.* I do: for sometimes the height of the water is 20 or 30 times greater on one side of the gates than it is on the other, therefore the pressure will be 400 or even 900 times greater against one side than it is against the other.

*Emma.* How are the gates opened when such a weight presses against them?

*Father.* No power could be well applied to move them when this weight of water is against them; therefore there are sluices by the side,

which being drawn up, the water gets away through them into the bason, till it becomes level on both sides; then the gates are opened with the greatest ease, because the pressure being equal on both sides, a small force applied will be sufficient to overcome the friction of the hinges or other trifling obstacles.

*Charles.* Is it this great pressure that sometimes beats down the banks of rivers?

*Father.* It is: for if the banks of a river or canal do not increase in strength in the proportion of the square of the depth, they cannot stand. Sometimes the water in a river will insinuate itself through the bank near the bottom, and if the weight of the bank be not equal to that of the water, it will assuredly

be torn up, perhaps with great violence.

I will make the matter clear by a figure. Suppose this figure (Plate II. Fig. 17.) be a section of a river, and  $c$  a crevice or drain made by time under the bank  $g$ ; by what we have shewn before, the upward pressure of the water in that drain is equal to the downward pressure of the water in the river; therefore if that part of the bank be not as heavy as a column of water the same height and width, it must be torn up by the force of the pressure.

*Charles.* Is there no method of securing leaks that happen in the embankments of rivers?

*Father.* The only method is that called *puddling*. If  $n$  be the bank of a canal in which a leak is discovered,

the water must be first drawn off below the leak, and a trench 18 or 20 inches wide dug length-wise along the side of the canal, and deeper than the bottom of the canal: this is filled, by a little at a time, with clay or loam reduced into a half fluid state by mixing it with water: when the first layer, which is seldom above six or eight inches deep, is nearly dry, another is worked in the same manner till the whole be filled. By this means, if the operation be performed by skilful hands, and time be allowed for all the parts to dry and cohere, the bank becomes strong and impenetrable.

## CONVERSATION IX.

---

*Of the Motion of Fluids.*

*FATHER.* I will now shew you an experiment by which you will observe the uniformity of nature's operations in regard to spouting fluids.

*Charles.* Do you refer to any other facts besides those which relate to the quantity of water issuing from pipes?

*Father.* Yes, I do. Let *A B* (Plate II. Fig. 18.) represent a tall vessel of water, which must be always kept full while the experiments are making. From the center of this

vessel I have drawn a semicircle, the diameter of which is the height of the vessel A B. I have drawn three lines,  $d 2$  from the center of the vessel;  $c 1$ ,  $a 5$ , at equal distances from the center, the one above and the other below it: all three are drawn perpendicular to the vessel. By taking out the plug from the center you will see the water spouts to  $m$ . Take your compasses and you will find that the distance  $N M$  is exactly double the length of  $d 2$ . I will now stop this plug and open the next below.

*Charles.* The water reaches to  $k$ , which is double the length of  $a 5$ .

*Father.* Try in the same manner the pipe  $c$ .

*Charles,* It falls at the same spot  $k$  as it did from the lower one.

*Father.* Because the lines  $c 1$  and  $a 5$  being equally distant from the center of the semicircle, they are equal to one another.

*Emma.* Then  $N K$  is the double of  $c 1$ , as well well as of  $a 5$ .

*Father.* It is. The general rule: deduced from these experiments is, that the horizontal distance to which a fluid will spout from an horizontal pipe, in any part of the side of an upright vessel below the surface of the fluid, is equal to twice the length of a perpendicular to the side of the vessel drawn from the mouth of the pipe to a semicircle described upon the altitude of the vessel.

Can you, Charles, tell me in what part the pipe should be placed, in order that the fluid should spout the farthest possible?

*Charles.* In the center: for the line  $d\ 2$  seems to be the greatest of all the lines that can be drawn from the vessel to the curved line.

*Father.* Yes, it is demonstrable by geometry that this is the case; and that lines at equal distances from the center above and below are also equal to each other.

*Emma.* Then in all cases, if pipes are placed equally distant from the center they will spout to the same point.

*Father.* They will. Instead of horizontal pipes, I will fix three others near  $N$ , which shall point obliquely upwards at different angles; one at  $22^{\circ} 30'$ , the second at  $45^{\circ}$ , and the third at  $67^{\circ} 30'$ , and you will see that when I open the cocks, the water will cut the curve line in those

places to which the horizontal lines were drawn.

*Charles.* That which spouts from the center is thrown to the point *M* as it was from the center horizontal pipe. The two others fall on the point *K*, on which the upper and lower horizontal pipes ejected the stream.

*Emma.* I thought the water from the upper cock did not reach so high as the mark.

*Father.* It did not. The reason is, that it had to pass through a larger body of air, and the resistance from that retarded the water and prevented it from ascending to the point to which it would have ascended if the air had been taken away.

While we are on this subject, I will just mention, that as you see the water spouts the farthest when the

pipe is elevated to an angle of  $45^\circ$ , so a gun, cannon, &c. will project a bullet the farthest if it be elevated to an angle of  $45^\circ$ .

*Charles.* Will a cannon or mortar carry a ball equally distant if it be elevated at angles equally distant from  $45^\circ$ , the one above and the other below?

*Father.* It will in theory: but owing to the great resistance which very swift motions meet with from the air, there must be allowances made for some considerable variation between theory and practice.

A regard to this will explain the reason why water will not rise so high in a jet as it does in a tube.

*Emma.* I do not know what this means.

*Father.* You have seen a fountain.

*Emma.* Yes, I have often been amused with that in the Temple.

*Father.* All fountains are called jets, or *jets d'eau*. Now if the water of that in the Temple ascended in a pipe, it would rise higher than it does in the open air. Turn to Fig. 10, the water in the small tube rises to a level with that in the larger one; now if the tube *h g* were broken off at *t*, the water would spout up like a fountain, but not so high as it stands in the tube, perhaps no higher than to *d*.

*Charles.* Is that owing wholly to the resistance of the air?

*Father.* It is to be ascribed to the resistance which the water meets with from the air, and to the force

of gravity, which has a tendency to retard the motion of the stream.

*Emma.* Why does the fountain in the Temple sometimes play higher and sometimes lower?

*Father.* Near the Temple-hall there is a reservoir of water, from which a pipe communicates with the jet in the fountain: and according as the water in the reservoir is higher or lower, the height to which the fountain plays is regulated.

*Charles.* By turning a cock near the pump the fountain is instantly lowered.

*Father.* That cock is likewise connected with the reservoir, and therefore taking water from it must have the effect of lowering the stream at the fountain, as well as that in the reservoir.

*Emma.* It soon recovers its force again.

*Father.* Because there is a constant supply of water to the reservoir, which, however, does not come in so quick as the cock lets it out, or the fountain would always play to the same height. ^

From what you have already learnt on this subject you will be able to know how London and other places are supplied with water

*Charles.* London is, I believe, supplied from the New-River, but I do not know in what manner.

*Father.* The New-River is a stream of water that comes from Ware in Hertfordshire; it runs into a reservoir situated on the high ground near Islington. From this reservoir pipes are laid into those parts of

town that have their water from the New-River, and through these pipes the water flows into cisterns belonging to different houses.

*Emma.* Then the reservoir at Islington must be higher than the cisterns in London.

*Father.* Certainly, because water will not rise above its level. On this account some of the higher parts of town have hitherto been supplied from the ponds at Hampstead; and others are supplied from the Thames, by means of the water works at London-Bridge.

*Charles.* Are pipes laid all the way from Hampstead to town?

*Father.* They are: but these supply the intermediate villages as well as London: and Hampstead standing so high, the water is carried up

into the first and second stories in some houses. Thus you see that water may be carried to any distance, and houses on different sides of a deep valley may be supplied by water from the same spring-head. You must remember that if the valleys are very deep the pipes must be exceedingly strong near the bottom, because the pressure increases in the rapid proportion of the odd numbers 1, 3, 5, 7, &c. and therefore unless the strength of the wood or iron be increased in the same proportion the pipes will be continually bursting.

*Emma.* You told me the other day, that the large mound of earth, for it appears nothing else, near the end of Tottenham-court-road, was intended as a reservoir for the New-River.

*Father.* What appears to you, and others who pass by it, only as a mound of earth, is an exceedingly large bason capable of containing a great many thousand hogsheads of water.

*Charles.* How will they get the water into it?

*Father.* At Islington, near the New-River-head, is made a large reservoir upon some very high ground, into which, by means of a steam-engine, they will constantly throw water from the New-River. This reservoir being higher than that in Tottenham-court-road, nothing more is necessary than to lay pipes from Islington to that place in order to keep it constantly full of water.

By this contrivance the New-River company will be able to extend their

business to other parts of London where their present head of water cannot reach.

*Charles.* The weight of water in this place must be immensely great.

*Father.* And therefore you observe what a thickness the mound of earth against the wall is towards the bottom, and that it diminishes towards the top as the pressure becomes less and less.

*Emma.* Would not the consequences be very serious if the water were to insinuate itself through the earth at the bottom?

*Father.* If such an accident were to happen when the reservoir was full of water, it would probably tear up the works and do incredible mischief. To prevent this, the vast bank of earth is sloped within, as well as

without; it will then be covered with a strong coating of clay; after this it will be built up with a very thick brick-wall, which will be carefully tarrassed over, so that the whole mass will be as firm and compact as a glass bottle.

CONVERSATION X.

---

*Of the specific Gravities of Bodies.*

*EMMA.* What is the reason, Papa, that some bodies, as lead or iron, if thrown into the water, sink, while others, as wood, will swim?

*Father.* Those bodies that are heavier than water will sink in it, but those that are lighter will swim?

*Emma* I do not quite comprehend your meaning; a pound of wood, another of water, and another of lead, are all equally heavy. For Charles played me a trick the other day: he suddenly asked which was

heavier, a pound of lead or a pound of feathers? I said the lead, and you all laughed at me, by which I was soon led to perceive, that a pound, or 16 ounces of any substance whatever, must be always equal to the same weight.

*Father.* You are not the first person that has been taken in by this question. It is a common trick. Although a pound of lead and another of water be equally heavy, yet they are not of equal magnitudes. Do you know how much water goes to a pound?

*Charles.* Yes; about a pint.

*Father.* Do you think that if I were to fill the same pint measure with lead, that would weigh a pound only.

*Charles.* Oh no ; that would weigh a great deal more. I do not believe that the 14 pound weight below stairs is much larger than a pint measure.

*Father.* Yes it is, by about a fourth part : the same measure that contains one pound of water, would, however, contain about 11 pounds of lead ; but it would contain 14 pounds of quicksilver, which, you know, I could as readily pour into the vessel as if it were water.

Here are two cups of equal size ; fill the one with water, and I will fill the other with quicksilver.

*Emma.* Why did you not let Charles pour out the quicksilver ?

*Father.* The loss of water is a matter of little consequence ; but if, by chance, he had thrown down the

quicksilver, the accident might have occasioned the loss of sixpence, or a shilling; and economy is right in all the affairs of life. Take the cups in your hand: which is the heavier?

*Charles.* The quicksilver by much.

*Father.* But the two cups are of equal size.

*Emma.* Then there must be equal quantities of water and quicksilver.

*Father.* They are equal in bulk.

*Charles.* But very unequal in weight: shall I try how much heavier the one is than the other.

*Father.* If you please. In what manner will you ascertain the matter?

*Charles.* I will carefully weigh the two cups, and then dividing the larger weight by the smaller, I shall

see how many times heavier the quicksilver is than the water.

*Father.* You will not come to the point accurately by that means ; because the weight of the cups is probably equal, but by this method they ought to differ in weight in the same proportion as the two substances.

*Emma.* Then pour the quicksilver first into the scale and weigh it ; afterwards do the same with the water ; and divide the former by the latter : will not that give the result ?

*Father.* Yes, it will : or you may make the experiment in this method.

Here is a small phial, that weighs, now it is empty, an ounce ; fill it with pure rain water, and the weight of the whole is two ounces.

*Charles.* Then it contains one ounce of water.

*Father.* Pour out the water, and let it be well dried both within and without; fill it now very accurately with quicksilver, and weigh it again.

*Emma.* It weighs a little more than 15 ounces: but as the bottle weighs one ounce, the quicksilver weighs something more than 14 ounces.

*Father.* What do you infer from this, Charles?

*Charles.* That the quicksilver is more than 14 times heavier than water.

*Father.* I will now pour away the quicksilver, and fill the phial with pure spirits of wine, or, as the chemists call it, with *alkohol*.

*Emma.* It does not weigh two ounces now ; consequently the fluid does not weigh an ounce. The alkohol is, then, lighter than water.

*Father.* By these means, which you cannot fail of understanding, we have obtained the *comparative weights* of three fluids : philosophers, as I have before told you, call these comparative weights, the *specific gravities* of the fluids : they have agreed also to make pure rain-water the standard to which they refer the comparative weights of all other bodies, whether solid or fluid.

*Charles.* Is there any particular reason why they prefer water to every other substance ?

*Father.* I told you a few days ago, that rain-water, if very pure, is

of the same weight in all parts of the world : and, what is very remarkable, a cubical foot of water weighs exactly a thousand ounces avoirdupoise : on these accounts it is admirably adapted for a standard, because you can at once tell the weight of a cubical foot of any other substance, if you know its specific gravity.

*Emma.* Then a cubical foot of quicksilver weighs 14,000 ounces.

*Father.* You are right ; and if lead is 11 times heavier than water, a cubical foot of it will weigh 11,000 ounces.

CONVERSATION XI.

---

*Of the specific Gravities of Bodies.*

*FATHER.* Before we enter upon the methods of obtaining the specific gravities of different bodies, it will be right to premise a few particulars, which it is necessary should be well understood.

You now understand, that the specific gravity of different bodies depends upon the different quantities of matter which equal bulks of these bodies contain.

*Charles.* As the *momenta* \* of different bodies are estimated by the quantities of matter when the velocities are the same; so the specific gravity of bodies is estimated by the quantities of matter when the bulks or magnitudes are the same. This, I believe, is what you mean.

*Father.* I do: if you had a piece of wood, and another piece of lead, both exactly equal in size to a copper penny-piece, the former would be much lighter, and the latter considerably heavier, than the copper.

*Charles.* And I should say that the specific gravity of the wood is less than that of the copper, but of the lead it is greater.

\* See Vol. I. Of Mechanics, Couper. VI.

*Emma.* Is it then the *density* that constitutes the specific gravity?

*Father.* Undoubtedly it is : and, as we observed yesterday, water is made use of as a medium to discover the different specific gravities of different bodies ; and also as a standard to which they may be all referred.

Here are three pieces of different kinds of wood, which I will put into this vessel of water : one sinks to the bottom ; a second remains in any position of the water in which it is placed ; and the third swims on the water with more than half of the substance above its surface.

*Charles.* The first, then, is heavier than the water, the second is of the same weight with an equal bulk of the fluid, and the third is lighter.

*Father.* Since fluids press in all directions, a solid that is immersed in water sustains a pressure on all sides, which is increased in proportion to the height of the fluid above the solid.

*Emma.* That seems natural, but an experiment would fix it better in the mind.

*Father.* Tie a leathern bag (Plate I. Fig. 8.) to the end of a glass tube, and pour in some quicksilver. Dip the bag in water, and the upward pressure of the fluid will raise the quicksilver in the tube, the ascent of which will be higher or lower, in proportion to the height of the water above the bag.

*Emma.* I now understand that the upper part of the tube being empty, or, at least, only filled with

air, the upward pressure of the water against the bag must be greater than the downward pressure of the air: and that as the pressure increases according to the depth, therefore the mercury must keep rising in the tube.

What is the reason that a body heavier than water, as a stone, sinks to the bottom, if the pressure upward is always equal to that downwards?

*Father.* This is a very proper question. The stone endeavours to descend by the force of gravity: but it cannot descend without moving away as much of the water as is equal to the bulk of the stone; therefore it is resisted, or pressed upwards, by a force equal to the weight of as much water as is equal in magnitude to the bulk of the stone: but the weight of:

the water is less than that of the stone, consequently the force pressing against it upwards is *less* than its tendency downwards, and therefore it will sink with the *difference* of these two forces.

You will now be at no loss to understand the reason why bodies lighter than water swim :

As passing straws and buoyant leaves  
 The yielding surface but receives ;  
 While pearls, that lure the searching eye,  
 Deep treasur'd in its bosom lie.  
 May trifles such reception find,  
 Float merely transient on my mind,  
 While weightier thoughts admission win,  
 Sink its whole depths, and rest within.

BROWNE.

*Charles.* The water being heavier, the force upwards is greater than the natural gravity of the body, and it will

be buoyed up by the difference of the forces.

*Father.* Bodies of this kind, then, will sink in water, till so much of them is below the surface, that a bulk of water equal to the bulk of the part of the body which is below the surface, is of a weight equal to the weight of the whole body.

*Emma.* Will you explain this more particularly ?

*Father.* Suppose the body to be a piece of wood, part of which will be above and part below the surface of the water ; in this state conceive the wood to be frozen into the water.

*Charles.* I understand you : if the wood be taken out of the ice, a vacuity will be left, and the quantity of water that is required to fill that

vacuity will weigh as much as the whole substance of the wood.

*Father.* That was what I meant to have said.

There is one case remaining:—where equal bulks of the water and the wood are of the same weight, the force with which the wood endeavours to descend, and the force that opposes it, being equal to one another, and acting in contrary directions, the body will rest between them, so as neither to sink by its own weight, nor to ascend by the upward pressure of the water.

*Emma.* What is the meaning of this glass jar with the images in it (Plate III. Fig. 19.)?

*Father.* I placed it on the table in order to illustrate our subject to-

day. You observe that, by pressing the bladder with my hand, the three images all sink.

*Emma.* But not at the same moment.

*Father.* The images are made of glass, and about the same specific gravity with the water surrounding them, or perhaps rather less than it, and consequently they all float near the surface. They are hollow, with little holes in the feet. When the air, which lies between the bladder and the surface of the water, is pressed by my hand, there is a pressure on the water which is communicated through it, and that part of it which lies contiguous to the feet of the images will be forced into their bodies, by which their weight is so much increased as to render them

heavier than the water, and they descend.

*Charles.* Why do they not all descend to the same depths?

*Father.* Because the hollow part of the image *E* is larger than the hollow part of *D*, and that is larger than that of *C*; consequently the same pressure will force more water into *E* than into *D*, and more into *D* than into *C*.

*Emma.* Why do they begin to ascend now you have taken your hand away?

*Father.* I said the hollow parts of the images were empty, which was not quite correct; they were full of air, which, as it could not escape, was compressed into a smaller space when the water was forced in by the pressure upon the bladder. But as

soon as the pressure is removed, the air in the images expands, drives out the water, and they become as light as at first, and will therefore rise to the surface.

*Charles.* The images in rising up to the surface turned round.

*Father.* This circular motion is owing to the hole being on one side; and when the pressure is taken off, the water issuing out quickly is resisted by the water in the vessel, and the reaction being exerted on one foot, turns the figure round.

CONVERSATION XII.

---

*Of the Methods of finding the specific Gravity of Bodies.*

*EMMA.* What are you going to weigh with these scales?

*Father.* This instrument (Plate III. Fig. 20.) is called the hydrostatical balance; it differs but little from the balance in common use. Some instruments of this kind are more complicated, but the most simple are best adapted to my purpose.

To the beam two scale-pans are adjusted, and may be taken off at

pleasure. There is also another pan A, of equal weight with one of the others, furnished with shorter strings and a small hook, so that any body may be hung to it, and then immersed in the vessel of water B.

*Charles.* Is it by means of this instrument that you find the specific gravity of different bodies?

*Father.* It is: I will first give you the rule, and then illustrate it by experiments. The rule should be committed to memory.

“ Weigh the body first in air; that is, in the common way; then weigh it in water; observe how much weight it loses by being weighed in water, and by dividing the former weight by the loss sustained, the result is its specific gravity, compared with that of the water.”

I will give you an example.—Here is a new guinea: it weighs in the air 129 grains: I suspend it by a fine thread of horse-hair to the hook at the bottom of the pan A, and you see that by being immersed in water it weighs only  $121\frac{3}{4}$  grains.

*Emma.* Then in the water it has lost of its weight  $7\frac{1}{4}$  grains.

*Father.* Divide 129 by  $7\frac{1}{4}$ , or, by turning the  $\frac{1}{4}$  into decimals, by 7.25.

*Charles.* But I must add two cyphers to the 129 grains, because there must always be as many decimals in the dividend as there are in the divisor. And 129.00 divided by 7.25 gives for the quotient more than 17.

*Father.* The gold is therefore more than 17 times heavier than water.

*Emma.* I do not understand the reason of this.

*Father.* In this scale is a bason filled accurately to the brim with water. I will put a piece of mahogany into it very gently; any thing else would answer the same purpose.

*Emma.* The water runs over into the scale.

*Father.* So I expected it would: now every thing is at rest, and the bason is just as full as it was at first, only that the wood and water together fill the bason, whereas it was all water before. I will take away the bason, and put the mahogany by itself into the other scale.

*Emma.* It balances the water that run out of the bason.

*Charles.* The mahogany then displaced a quantity of water equal to itself in weight.

*Father.* And so did the guinea just now; and if you had taken the same precaution, you would have found that the quantity of water equal in bulk to the guinea weighed  $7\frac{1}{4}$  grains, the weight which it lost by being weighed in the fluid.

*Emma.* Am I to understand that what any substance loses of its weight, by being immersed in water, is equal to the weight of a quantity of water of the same bulk as the substance itself?

*Father.* This is true, if the body be wholly immersed in water; and with regard to all substances that are specifically heavier than water, you may take it as an axiom, that “every  
“ body, when immersed in water,  
“ loses as much of its weight, as is

“ equal to the weight of a bulk of  
“ water of the same magnitude.”

I will now place this empty box on the bason filled to the edge with water, and, as before, it drives over a quantity of the fluid equal in weight to itself. Put in two penny-pieces, and you perceive the box sinks deeper into the water.

*Charles.* And they drive more water over; as much, I suppose, as is equal in weight to the copper coin.

*Father.* Right: how long could you go on loading the box?

*Charles.* Till the weight of the copper and box, taken together, is something greater than the weight of as much water as is equal in bulk to the box.

*Father.* You understand, then, the reason why boats, barges, and other vessels, swim on water; and to what extent you may load them with safety.

*Emma.* They will swim so long as the weight of the vessel and its lading together, is less than that of a quantity of water equal in bulk to the vessel.

*Father.* Can you, Charles, devise any method to make iron or lead swim, which are so much heavier than water?

*Charles.* I think I can. If the metal be beat out very thin, and the edges turned up, I can easily conceive that a box or a boat of it may be made to swim. Of this kind is the copper ball which is contrived to

turn off the water when the cistern is full.

*Emma.* I have often wondered how that acts.

*Father.* If upon reflection you could not satisfy yourself about the mode of its acting, you should have asked ; it is better to get information from another than to remain ignorant.

The ball, though made of copper, which is eight or nine times heavier than water, is beat out so thin, that its bulk is much lighter than an equal bulk of water. By means of a handle it is fastened to the cock, through which the water flows, and as it sinks or rises, it opens or shuts the cock.

If the cistern is empty, the ball

hangs down, and the cock is open, to admit the water freely : as the water rises in the cistern it reaches the ball, which, being lighter than the water, rises with it, and, by rising, gradually shuts the cock, and, if it be properly placed, it is contrived to shut the cock just at the moment that the cistern is full.

In the same way that these balls are made, boats of iron are now constructed at the iron-works in Shropshire : they will last longer than wood, and cause less friction in passing through the water.

Can you, Emma, find the specific gravity of this piece of silver ?

*Emma.* It weighs in air 318 grains : I now fasten it to the hook with the horse-hair, and it weighs in water 288 grains, which, taken from

318, leave 30, the weight it lost in water. By dividing 318 by 30, the quotient is about  $10\frac{1}{2}$ , consequently the specific gravity of the silver is ten and a half times greater than that of water.

*Father.* What is the specific gravity of this piece of flint-glass? It weighs 12 pennyweights in air.

*Charles.* And in water it weighs only 8, and consequently loses 4 by immersion; and 12 divided by 4 gives 3, therefore the specific gravity of flint-glass is 3 times greater than that of water.

*Father.* This is not the case with all flint-glass; it varies from 2 to almost 4.

Here is an ounce of quicksilver; let me know its specific gravity by the method now proposed.

*Emma.* How will you manage that? you cannot hang it upon the balance.

*Father.* But you may suspend this glass bucket (Plate III. Fig. 21.) on the hook at the bottom of A; immerse it in the water, and then balance it exactly with weights in the opposite scale.

I will now put into the bucket the ounce, or 480 grains of quicksilver, and see how much it loses in water.

*Charles.* It weighs 445 grains, and consequently it lost 35 grains by immersion; and 480 divided by 35 give almost 14, so that mercury is almost 14 times heavier than water.

*Father.* In the same manner we obtain the specific gravity of all bodies that consist of small fragments. They must be put into the glass

bucket and weighed; and then if from the weight of the bucket and body in the fluid, you subtract the weight of the bucket, there remains the weight of the body in the fluid.

*Emma.* Why do you make use of horse-hair to suspend the substances with; would not silk or thread do as well?

*Father.* Horse-hair is by much the best, for it is very nearly of the same specific gravity of water; and its substance is of such a nature as not to imbibe moisture.

CONVERSATION XIII.

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*Of the Methods of finding the specific Gravity of Bodies.*

*CHARLES.* I have endeavoured to find out the specific gravity of this piece of beech-wood, but as it will not sink in the water I know not how to do it.

*Father.* It is true that we have hitherto only given rules for the finding of the specific gravity of bodies that are heavier than water; a little consideration, however, will shew you

how to obtain the specific gravity of the beech. Can you contrive means to sink the beech in the water?

*Charles.* Yes; if I join a piece of lead, or other metal, to the wood, it will sink.

*Father.* The beech weighs 660 grains; I will annex to it an ounce, or 480 grains of tin, which in water loses of its weight 51 grains. In air the weight of the wood and metal taken together is 1140 grains; but in water they weigh but 138 grains: 138 taken from 1140 leave 1002, the difference between the weights in air and in water.

*Charles.* I now see the mode of finding what I want. The whole mass loses 1002 grains by immersion, and the tin by itself lost in water 51 grains; therefore the wood lost 951

grains of its weight by immersion : and 660 grains, the weight of the beech in air, divided by 951, which it may be said to lose by immersion, leaves in decimals for a quotient .694.

*Father.* Then making water the standard equal to 1, the beech is .694, or nearly  $\frac{7}{10}$ ths of 1 : that is, a cubic foot of water is to a cubic foot of beech as 1000 to 694, for the one weighs 1000 ounces, and the other 694 ounces.

*Emma.* It seems odd how a piece of wood that weighs but 660 grains in air, should lose of its weight 951 grains.

*Father.* You must, in this case, consider the weight necessary to make it sink in water, which must be added to the weight of the wood.

I will now endeavour to make the subject easier by a different method.

This small piece of elm I will place between the tongs (Plate III. Fig. 22.) that are nicely balanced on the beam, Fig. 20. The elm weighs 36 grains. To detain it under water, I must hang 24 grains to the end of the lever on which the tongs are fixed: then by the Rule of Three I say, as the specific gravity of the elm is to the specific gravity of water, so is 36, the weight of the elm, to 60, the weight of the elm and the additional weight required to sink it in water, or as  $60 : 36 :: S. G. W. S. G. E.$

*Emma.* You have not obtained the specific gravity of the elm, but a proportion only.

*Charles.* But three terms are given, because the water is also in

considered as unity or 1, therefore the specific gravity of the elm is

$$\frac{36 \times 1}{60} = .6.$$

*Emma.* I do not yet comprehend the reason of the proportion assumed.

*Father.* It is very simple. The elm is lighter than the water, but by hanging weights to the side of the balance, to which it is detached in order to detain it just under water, I make the whole exactly equal to the specific gravity of the water; by this means it is evident, that the comparative gravity of the elm is to that of the water as 36 to 60.

Try this piece of cork in the same manner.

*Emma.* It weighs  $\frac{1}{2}$  an ounce, or 240 grains, in air; and to detain the

cork and tongs just under water, I am obliged to hang 2 ounces, or 960 grains, of lead on the lever: therefore the specific gravity of the cork is to that of the water as 240 is to 1200; and 240 divided by 1200 give the decimal .2.

*Father.* Then the specific gravity of water is 5 times greater than that of cork.

*Charles.* We have now obtained the specific gravities of water, beech, elm, and cork, which are as 1, .7 nearly .6 and .2.

*Father.* You now understand the methods of obtaining the specific gravity of all solids, whether lighter or heavier than water. In making experiments upon light and porous woods, the operations must be performed as quickly as possible, to

prevent the water from getting into the pores.

*Charles.* And you have likewise shewn us a method of getting the specific gravity of fluids, by weighing certain quantities of each.

*Father.* I have a still better method: the rule I will give in words: you shall illustrate it by examples.

“ If the same body be weighed in  
“ different fluids, the specific gra-  
“ vity of the fluids will be as the  
“ weights lost.”

*Emma.* The body made use of must be heavier than the fluids.

*Father.* Certainly: this glass ball loses of its weight, by immersion in water, 803 grains; in milk it loses 831 grains; therefore the specific gravity of the water is to that of milk as 803 to 831. Now a cubical foot

of water weighs 1000 ounces ; what will be the weight of the same quantity of milk ?

*Emma.* As  $803 : 831 :: 1000 :$   
 $\frac{1000 \times 831}{803} = 1035$  ounces nearly.

*Father.* Do you, Charles, tell me what is the specific gravity of some spirits of wine which I have here.

*Charles.* The glass loses in water 803 grains, in the spirit of wine it loses 699 grains, therefore the specific gravity of water is to the spirit as 803 is to 699 ; and to find the weight of a cubical foot of the spirit, I say, as  
 $803 : 699 :: 1000 : \frac{1000 \times 699}{803} =$

870 ounces.

*Father.* You may now deduce the method of comparing the specific gravities of solids one with ano-

ther without making a common standard.

Here is an ounce of lead and another of tin : I may weigh them in any fluid whatever : in water the lead loses by immersion 42 grains, and the tin 63 grains.

*Emma.* Is the specific gravity of the lead to that of the tin as 42 to 63?

*Father.* No : “ the specific gravities of bodies are to one another *inversely* as the losses of weight sustained :” therefore the specific gravity of the lead is to that of the tin as 63 to 42 ; or if a block of lead weighs 63 pounds, the same sized block of tin will weigh 42 pounds only.

*Charles.* I think I see the reason of this : the heavier the body, the

less it loses of its weight by immersion ; therefore, of two bodies whose absolute weights are the same, that is, each weighing an ounce, pound, &c. the one which loses least of its weight will be the most specifically heavy.

*Father.* You are right ; for the specific gravity of bodies is as their density, and their densities are inversely as the weights they lose by immersion ; that is, the body that is most dense will lose the least in water,

## CONVERSATION XIV.

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*Of the Methods of obtaining the  
Specific Gravity of Bodies.*

*FATHER.* As I have shewn you the methods of finding the specific gravity of almost all kinds of bodies, it will be proper in this, and one or two lessons, to shew you the practical utility of this part of science.

*Emma.* To whom are we indebted for the discovery of the mode of performing these operations?

*Father.* To that most celebrated mathematician of antiquity, Archimedes.

*Charles.* Was he not slain by a common soldier at the siege of Syracuse?

*Father.* He was, to the great grief of Marcellus, the Roman commander, who had ordered that his house and person should be respected: but the philosopher was too deeply engaged in solving some geometrical inquiries to think of seeking that protection which even the enemy intended for him.

*Emma.* Had he at that time so high a reputation as to induce the general of a besieging army to give particular orders for his preservation?

*Father.* His celebrity was so great among the literati of Rome, that his tragical end caused more real sorrow than the capture of the whole island of Sicily did joy.

We are informed by history, that it was by the wisdom of Archimedes that the fate of Syracuse was long suspended : by his inventions multitudes of the Roman army were killed, and their ships destroyed : and it is added that he made use of burning glasses, which, at the distance of some hundreds of yards, set the Roman vessels on fire \*.

*Charles.* I wonder then that he was not defended by his fellow-citizens.

*Father.* Alas ! my child, I am sorry to say, that in other countries as well as Sicily, there have been instances in which persons, who have

\* We shall consider this subject at large in our conversations on Optics.

benefited their country as much as Archimedes, have experienced no more gratitude than he did.

It is a fortunate circumstance when the efforts of philosophy are directed, under able judgment, to the defence of one's country. The Romans had no more right to plunder Sicily than the highwayman has to rifle your pockets or mine. In the eye of reason and justice all *offensive* war is the most deliberate and cruel system of robbery and murder.

But to return to our subject. To Archimedes the world is indebted for the discovery, "That every body  
" heavier than its bulk of water,  
" loses so much of its weight, by  
" being suspended in water, as is  
" equal to the weight of a quantity  
" of water equal to its bulk."

*Emma.* How did he make the discovery?

*Father.* Hiero, king of Syracuse, had given to a jeweller a certain quantity of pure gold, to make a crown for him. The monarch, when he saw the crown, suspected the artist of having kept back part of the gold.

*Emma.* Why did he not weigh it?

*Father.* He did; and found the weight right: but he suspected, perhaps from the colour of the crown, that some baser metal had been mixed with the gold, and therefore though he had his weight, yet only a part of it was gold, the rest silver or copper. He applied to Archimedes to investigate the fraud.

*Charles.* Did he melt the crown, and endeavour to separate the metals?

*Father.* That would not have answered Hiero's intentions : his object was to detect the roguery, if any, without destroying the workmanship. While the philosopher was intent upon the problem, he went, according to his custom, into the bath, and he observed that a quantity of water flowed over, which he thought must be equal to the bulk of his own body. He instantly saw the solution of Hiero's problem. In raptures at the discovery, he is said to have leaped from the water and run naked through the streets of the city, shouting aloud *Εὐρηκα ! Εὐρηκα !* " I have found it out ! " " I have found it out ! "

When the excess of his joy was abated, he got two masses, one of gold, and the other of silver, each equal in weight to the crown, and

having filled a vessel very accurately with water, into which he first dipped the silver mass and observed the quantity of water that flowed over: he then did the same with the gold, and found that a less quantity of water had flowed over than before.

*Charles.* And was he, from these trials, led to conclude that the bulk of the silver was greater than that of the gold?

*Father.* He was. And also that the bulk of water displaced was, in each experiment, equal to the bulk of the metal. He then made the same trial with the crown, and found, that though of the same weight with the masses of silver and gold, yet it displaced more water than the gold, and less than the silver.

*Emma.* Accordingly he concluded, I imagine, that it was neither pure gold nor pure silver.

*Charles.* But how could he discover the proportions of each metal?

*Father.* I believe we have no other facts to carry us farther into the history of this interesting experiment. But to-morrow I will endeavour to explain and illustrate the matter.

## CONVERSATION XV.

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*Of the Methods of obtaining the specific Gravity of Bodies.*

*EMMA.* You are to describe, to-day, the method of detecting the proportion of each metal if two are mixed together in one mass.

*Father.* Suppose I take in charge a guinea, which I suspect to be bad: upon trying it I find it weighs 129 grains, which is the standard weight of a guinea. I then weigh it in water, and it loses of its weight  $8\frac{1}{4}$  grains, by which I divide the 129, and the quotient is 15.6, the specific

gravity of the guinea. But you know the specific gravity of the gold, in Tower made guineas, is more than 17, and therefore I conclude the guinea is base metal, a mixture of silver, or copper, with standard gold.

*Charles.* But how will you get the proportions of the two metals?

*Father.* Suppose, for example, that the mass be a compound of silver and gold.—“ Compute what the loss of  
“ a mass of standard gold would be ;  
“ and likewise the loss which a mass  
“ of silver equal in weight to the  
“ guinea would sustain. Subtract  
“ the loss of the gold from that  
“ of the compound, the remainder  
“ is the ratio or proportion (not the  
“ quantity) of the silver : then sub-  
“ tract the loss of the compound  
“ from that of the silver, the re-

“mainder is the proportion of the  
“gold.” I will propose you an example.

What are the proportions of silver and gold in a guinea weighing 129 grains, whose specific gravity is found to be only 13.09; supposing the loss of standard gold 7.25, and that of a piece of silver, equal in weight to a guinea, 12.45, and the loss of the compound 9.85?

*Charles.* I first subtract the loss of standard gold 7.25 from the loss of the compound 9.85, the remainder is 2.6: I now take the loss of the compound 9.85, from that sustained by the silver 12.45, and the remainder is also 2.6.

*Father.* Then the proportions of silver and gold are equal to one ano-

ther, consequently the false guinea is half standard gold and half silver.

Here is another counterfeit guinea, which is full weight, but I know it is composed of standard gold, adulterated with copper, and its loss in water is, as you see, 8.64: now tell me the proportions of the two metals; but you should be informed that a piece of copper of the weight of a guinea would lose in water 14.65 grains.

*Emma.* I deduct 7.25, the loss of a guinea standard gold, from 8.64, the remainder is 1.39: I now take the loss of the compound 8.64 from 14.65, the loss sustained by a piece of copper equal in weight to a guinea, and the remainder is 6.01. Is not the proportion of copper to gold as 1.39 to 6.01?

*Father.* You are quite right. Now by the rule of three tell me the quantity of each metal.

*Emma.* To find the weight of the copper, I add 6.01 and 1.39 together, which are the *proportional* weights of the two metals. And say, as 7.40, the sum, is to 1.39, the *proportional weight* of copper, so is the weight of the guinea 129 grains to the *real weight* of copper contained in the counterfeit guinea: but  $\frac{1.39 \times 129}{7.40} = 24.1$ , therefore there is a little more than 24 grains of copper in the compound.

*Father.* You have found then that there are 24 grains of copper in this counterfeit guinea. How will you find the weight of the gold?

*Emma.* Very easily : for if the composition be copper and gold, and there are found to be 24 grains of copper, there must be 105 of gold.

*Charles.* I have a question to propose. If by chance you take a bad guinea, (I have heard you say that you never attempt to pass it upon others,) how should you be able to ascertain the value it would fetch at the goldsmith's?

*Father.* It is certainly very wrong knowingly to pass bad money upon the public : no man has a right to commit an injury because he has received one ; if, therefore, I have taken counterfeit money, I ought to abide by the loss, rather than run the risk of injuring my neighbour : besides, in the course of circulation, a bad guinea, or a seven shilling piece,

or even coins of much less value, may fall into the hands of a poor and industrious family, which they perhaps laid by to answer the extraordinary demands of sickness; and, at that period of distress, not being able to say from whom they received the counterfeit coin, they may possibly be reduced to serious and pitiable difficulties: and therefore it is better for me to put up with the loss than run the hazard of injuring the poor.

Now to answer your question. A piece of copper, of equal weight with a guinea, loses of its weight in water 14.65 grains, 7 4 more than is lost by a standard guinea. The value of a standard guinea is 252 pence, divide therefore 252 by 7.4 and you get 34, the number of pence that is deducted, from the value of a guinea,

for every grain it loses more than it would lose if it were sterling gold.

*Emma.* In the guinea that lost 8.64 how much must be deducted from the real value of a guinea standard gold?

*Charles.* I can tell that; subtract 7.25 from 8.64 the remainder is 1.39, and this multiplied by 34 pence gives 47.26 pence, or very nearly 4 shillings, consequently that guinea is worth only 17 shillings.

*Father.* Suppose the compound were silver and gold, how would you proceed in making an estimate of its value?

*Charles.* A piece of silver of the weight of a guinea would lose 12.45 grains, from which I deduct 7 25, and with the remainder 5.2 I divide the value of a guinea, or 252 pence,

and the quotient is 48.4 pence, or rather more than 4 shillings is to be deducted from the value of a guinea adulterated with silver, for every grain it loses by immersion more than standard gold.

*Emma.* How is that Papa? silver is much dearer than copper, and yet you allow 4 shillings a grain when the guinea is alloyed with silver, and but 2s. 10d. when the mixture is made with copper?

*Father.* Because the specific gravity of silver is much nearer to that of gold, than that of copper, consequently if equal quantities of silver and copper were mixed with gold the silver would cause a much less loss by immersion in water than the copper.

As it seldom happens that the adulteration of metal in guineas is

made with all copper, or with all silver, but generally with a mixture of both, three shillings is upon the average allowed for every grain that the base metal loses by immersion in water more than sterling gold.

*Emma.* There is a silver cream jug in the parlour; I have heard Mamma say, she did not think it was real silver; how could she find out whether she has been imposed on?

*Father.* Go and fetch it. We will now weigh it.

*Emma.* It weighs  $5\frac{1}{2}$  ounces, but I must weigh it in water, and it has lost in the water  $10\frac{1}{4}$  dwts; and dividing  $5\frac{1}{2}$  ounces, or 110 pennyweights by  $10\frac{1}{4}$ , I get for answer 10.7, the specific gravity of the jug.

*Father.* Then there is no cause for complaint, for the specific gravity of good wrought silver is seldom more than this.

*Table of Specific Gravities.*

Distilled water .....	1.000
Sea-water .....	1.026
Standard gold .....	17.486
Mercury .....	13.568
Standard silver .....	10.391
Lead .....	11.352
Brass .....	8.396
Copper .....	7.788
Tin .....	7.291
Iron (cast) .....	7.207
Iron (bar) .....	7.788
Zinc .....	7.191
Flint-glass .....	3.250
Ivory .....	1.825
Oil .....	.940
Cork .....	.240

## CONVERSATION XVI.

---

*Of the Hydrometer.*

*FATHER.* Before I describe the construction and uses of the hydrometer, I will shew you an experiment or two which will afford you entertainment, after the dry calculations in some of our former conversations.

*Charles.* . The arithmetical operations are rather tedious to be sure, but they serve to bring to mind what we have already learnt, and at the same time shew to what uses arithmetic may be applied.

*Father.* You know that wine is specifically lighter than water, and the lighter body will always be uppermost: upon these principles, I will exhibit two or three experiments. I have filled the bulb *B* (Plate III. Fig. 23.) with port wine to the top of the narrow stem *x*. I now fill *A* with water.

*Emma.* The wine is gradually ascending like a fine red thread through the water to its surface.

*Father.* And so it will continue till the water and wine have changed places.

*Charles.* I wonder the two liquids do not mix, as wine and water do in a common drinking glass.

*Father.* It is the narrowness of the stem *x* which prevents the admixture: in time, however, this

would be effected, because water and wine have what the chemists call an attraction for each other.

Here is a small bottle *B* (Plate III. Fig. 24.) with a neck three inches long, and about one sixth of an inch wide; it is full of red wine. I will now place it at the bottom of a jar of water, a few inches deeper than the bottle is high. The wine you observe is ascending through the water.

*Emma.* This is a very pretty experiment: the wine rises in a small column to the surface of the water, spreading itself over it like a cloud.

*Father.* Now reverse the experiment: fill the bottle with water, and plunge its neck quickly into a glass of wine; the wine is taking place of the water.

*Charles.* Could you decanter a bottle of wine in this way without turning it up?

*Father.* I could if the neck of the decanter were sufficiently small. The negroes in the West-Indies are said to be well acquainted with this part of hydrostatics, and that they plunder their masters of rum by filling a common bottle with water and plunging the neck of it into the bung-hole of the hogshead.

*Emma.* Poor creatures, they ought to have something to console them for the miseries they endure.

*Father.* Indeed the cruelties that are in general exercised upon the slaves, very much extenuate the crime of pilfering of which they are said to be guilty.

Upon the principle of lighter fluids keeping the uppermost parts of a vessel, several fluids may be placed upon one another in the same vessel without mixing: thus in a long upright jar three or four inches in diameter, I can place water first, then port-wine, then oil, brandy, oil of turpentine, and alkohol.

*Charles.* How would you pour them in one upon another without mixing?

*Father.* This will require a little dexterity: when the water is in, I lay a piece of very thin pasteboard upon its surface, and then pour in the wine; after which I take away the pasteboard, and proceed in the same manner with the rest. Take a common goblet or drinking glass, pour water in, and then lay a thin piece

of toasted bread upon the water, and you may pour your wine upon the bread, and the two fluids will remain for some time separate.

*Emma.* Is the toast placed merely to receive the shock of the wine when poured in?

*Father.* That is the reason. Now I will proceed to explain the principle of the *hydrometer*, an instrument contrived to ascertain with accuracy and expedition the specific gravities of different fluids.

A B (Plate III. Fig. 25.) is a hollow cylindrical tube of glass, ivory, copper, &c. five or six inches long, annexed to a hollow sphere of copper D: to the bottom of this is united a smaller sphere E, containing a little quicksilver, or a few leaden shot suf-

ficient to poise the machine, and make it sink vertically in the fluid.

*Charles.* What are the marks on the tube?

*Father.* They are degrees exhibiting the magnitudes of the part below the surface, consequently the specific gravity of the fluid in which it descends. If the hydrometer, when placed in water, sink to the figure 10, and in spirit of wine to 11.1, then the specific gravity of the water is to that of the spirit, as 11.1 to 10: for if the same body float upon different fluids, the specific gravity of these fluids will be to each other *inversely* as the parts of the body immersed.

*Emma.* By *inversely*, do you mean that the fluid in which the hydro-

meter sinks the deepest is of the least specific gravity?

*Father.* Yes I do : here is a piece of dry oak, which if I put into spirits of wine is entirely immersed ; in water the greatest part of it sinks below the surface ; but in mercury it scarcely sinks at all. Hence it is evident that the hydrometer will sink deepest in the fluid that is of the least specific gravity.

To render this instrument of more service, a small stem is fixed at the end of the tube, upon which weights like that at *g* may be placed. Suppose then the weight of the instrument is 10 dwts., and by being placed in any kind of spirit it sinks to a certain point *L*, it will require an additional weight, suppose 1.6 dwt. to sink it to the same depth in water :

in this case the specific gravity of the water to the spirit will be as 11.6 to 10. By the addition of different weights the specific gravity of any kind of liquor is easily found. The point L should be so placed as to mark the exact depth to which the instrument will sink in the liquor that has the least specific gravity.

*Charles.* But you always make the specific gravity of water 1 for the sake of a standard.

*Father.* Right: and to find the specific gravity of the spirit compared with water at 1; I say as  $11.6 : 1 :: 10 : .862$  nearly, so that I should put the specific gravity of this spirit down at .862 in a table where water was marked 1: and as a cubic foot of water weighs 1000 ounces, a cubic foot of this spirit would weigh 862

ounces, which is generally the standard of pure *rectified spirit*.

*Emma.* Is this what is usually called spirits of wine?

*Father.* No: it is the alkohol of the chemists, one pint of which added to a pint of water make a quart *nearly* of common spirits of wine.

*Charles.* You said .862 was *generally* the specific gravity of alkohol: what causes the difference at other times?

*Father.* It is not always manufactured of equal strength: and the same fluids vary in respect to their specific gravity by the different degrees of heat and cold in the atmosphere. The cold of winter condenses the fluid and increases the specific gravity; the heat of summer cause

an expansion of the fluid, and a diminution of its specific gravity.

*Emma.* You said just now that a pint of water added to a pint of alcohol made *nearly* a quart of spirits of wine, surely two pints make a *full* quart.

*Father.* Indeed they will not. A pint of water added to a pint of water will make a quart; and a pint of spirit added to a pint of spirit will make a quart; but mix a pint of spirit with a pint of water, and there is a certain chemical union or penetration between the particles of the two fluids, so that they will not make a quart. 'This subject we shall resume in our chemical conversations.

CONVERSATION XVII.

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*Of the Hydrometer, and Swimming.*

*CHARLES.* To what purposes is the hydrometer applied?

*Father.* It is used in breweries and distilleries to ascertain the strength of their different liquors: and by this instrument the excise officers guage the spirits, and thereby determine the duties to be paid to the revenue.

I think from the time we have spent in considering the specific gravity of different bodies, you will be at

no loss to account for a variety of circumstances that will present themselves to your attention in the common concerns of life. Can you, Emma, explain the theory of floating vessels?

*Emma.* All bodies whatever that float on the surface of the water displace as much fluid as is equal in weight to the weight of the bodies: therefore in order that a vessel may keep above water, it is only necessary to take care that the vessel and its cargo, passengers, &c. should be of less weight than the weight of a quantity of water equal in bulk to that part of the vessel which it will be safe to immerge in the water.

*Father.* Salt water, that is, the water in the sea, is specifically heavier than fresh or river water.

*Charles.* Then the vessel will not sink so deep at sea as it does in the Thames.

*Father.* That is true ; if a ship is laden at Sunderland, or any other sea-port, with as much coals or corn as it can carry, it will come very safely till it reach the fresh water in the Thames, and there it will infallibly go to the bottom unless some of the cargo be taken out.

*Emma.* How much heavier is sea water than the fresh ?

*Father.* About one thirtieth part, which would be a guide to the master of a vessel, who was bent upon freighting it as deeply as possible.

*Charles.* In bathing, I have often tried to swim, but have not yet been able to accomplish the task : is my

body specifically heavier than the water?

*Father.* I hope you will learn to swim, and well too; it may be the means of saving your own life, and rescuing others who are in danger of drowning:

————— Life is oft preserv'd  
By the bold swimmer in the swift lapse  
Of accident disast'rous. THOMSON.

By some very accurate experiments made by Mr. Robertson, the late librarian of the Royal Society, upon ten different persons, the mean specific gravity of the human body was found to be about  $\frac{1}{5}$ th less than that of common river water.

*Charles.* Why then do I sink to the bottom? I ought to swim like wood on the surface.

*Father.* Though you are specifically lighter than water, yet it will require some skill to throw yourself into such a position as to cause you to float like wood.

*Charles.* What is that position?

*Father.* Dr. Franklin recommends a person to throw himself in a slanting position on his back, but his whole body, except the face, should be kept under water. And Thomson describes a youth swimming, who

———— through the obedient wave,  
At each short breathing by his lip repell'd,  
With arms and legs according well, he makes,  
As humour leads, an easy winding path.

SUMMER.

Unskilful persons in the act of attempting this are apt to plunge about and struggle: by this means they

take water in at their mouths and nostrils, which of itself would soon render them as heavy or heavier than the water. Moreover the coldness of the stream tends to contract the body ; perhaps fear has the same tendency ; all these things put together will easily account for a person sinking in the water.

*Emma.* But if a dog or cat be thrown into the pond they seem as terrified as I should be in a like situation, yet they never fail of making their way out by swimming.

*Father.* Of all land animals man is, probably, the most helpless in this element. The brute creation swim naturally, the human race must acquire the art by practice. In other animals the trunk of the body is large, and their extremities small :

in man it is the reverse, the arms and legs are small in proportion to the bulk of the body, but the specific gravity of the extremities is greater than that of the trunk, consequently it will be more difficult for man to keep above water than for four footed animals: besides, the act of swimming seems more natural to them than to us, as it corresponds more nearly to their mode of walking and running than to ours.

*Charles.* I will try the next time I bathe to throw myself on my back according to Dr. Franklin's directions.

*Father.* Do not forget to make your experiments in water that is not so deep as you are high by at least a foot, unless you have an experienced person with you: because an unsuc-

cessful experiment in this element where it is but a little out of your depth may be the last you will make. And neither your sister nor I can spare you yet.

*Charles.* I once jumped into a part of the New-River, which I thought did not appear deeper than you say, and I found it was over my head, but there were several persons there who soon put me in shallower water.

*Father.* It is not so generally known as it ought to be, that the depth of a clear stream of water is always one-fourth part greater than it appears to be\*.

*Charles.* If the river appear to

\* The reason of this deception will be explained in our conversations on Optics.

be only three feet deep, may I reckon upon its being full four feet?

*Father.* You must estimate it in this manner. Remember also that if a person sink slowly in water ever so deep, a small effort will bring him up again, and if he be then able to throw himself on his back, keeping only his face above water, all will be well: but if instead of this he is alarmed, and by struggling throw himself so high above the water that his body does not displace so much of it as is equal to its weight, he will sink with an accelerated motion: a still stronger effort, which the sense of danger will inspire, may bring him up again, but in two or three efforts of this kind his strength fails, and he sinks to rise no more alive.

*Emma.* Is it the upward pressure which brings up a person that is at a considerable depth in the water?

*Father.* It is: this upward pressure balances the weight of water which he sustains, or he would be crushed to pieces by it.

Cork an empty bottle ever so well, and with weights plunge it down an hundred yards into the sea, and the pressure of the water will force the cork into the bottle.

## CONVERSATION XVIII.

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*Of the Syphon.*

*FATHER.* This bended tube (Plate III. Fig. 26.) is called a syphon, and it is used to draw off water, wine, or other fluids, from vessels which it would be inconvenient to move from the place in which they stand.

*Charles.* I do not see how it can draw liquor out of any vessel :—why is one leg longer than the other?

*Father.* I will first shew you how the operation is performed, and then endeavour to explain the principle.

I fill the tube *E D C* with water, and then placing a finger on *E*, and another on *c*, I invert the tube, and immerse the shorter leg into a jar of water ; and having taken my fingers away, you see the water runs over in a stream.

*Emma.* Will it continue to flow over ?

*Father.* It will till the water in the vessel come as low as *E*, the edge of the syphon.

*Charles.* Is this accounted for by pressure ?

*Father.* To the pressure or weight of the atmosphere we are indebted for the action of the syphon, pumps, &c. At present you must take it for granted that the air which we breathe, though invisible, has weight, and that the pressure, occasioned by

it, is equal to about 14 or 15 pounds upon every square inch \*. The surface of this table is equal to about six square feet, or 864 square inches, and the pressure of the atmosphere upon it is equal to at least 12096 pounds.

*Emma.* How does the pressure of the air cause the water to run through the syphon?

*Father.* The principle of the syphon is this: the two legs are of unequal length, consequently the weight of water in the longer leg is greater than that in the shorter, and therefore will, by its own gravity, run out at c, leaving a vacuum from d to e,

\* If any of my young readers are unwilling to admit this assertion without proof, they must be referred to the beginning of the fourth volume of these dialogues, for a complete demonstration of the fact.

did not the pressure of the atmosphere on the surface of the water in the jar force it up the leg  $DE$ , and thus continually supply the place of the water in  $DC$ .

*Charles.* But since the pressure of fluids acts in all directions, is not the upward pressure of the atmosphere against  $c$ , the mouth of the tube, equal to the downward pressure on the surface of the water?

*Father.* The pressure of the atmosphere may be considered as equal in both cases. But these equal pressures are counteracted by the pressures of the two unequal columns of water,  $DE$  and  $DC$ . And since the atmospheric pressure is more than sufficient to balance both these columns of fluid, that which acts with the lesser force, that is, the column

$D E$ , will be more pressed against  $D C$  than  $D C$  is against  $D E$  at the vertex  $D$ ; consequently the column  $D E$  will yield to the greater pressure, and flow off through the orifice  $c$ .

*Emma.* Would the same thing happen if the outer leg  $D C$  were shorter than the other?

*Father.* If  $D C$  were broken off at  $B$ , even with the surface of the water, no water would run over: or if it were broken off any where lower than  $B$ , it would only run away till the surface of the fluid descended to a level with the length of the outer tube, because then the column  $D E$  will be no more pressed against  $D C$ , than  $D C$  is against  $D E$ , and consequently the syphon will empty itself; the water in the outer leg will run out at the lower orifice, and that

in the inner will fall back into the jar.

*Charles.* In decanting a bottle of wine, are you obliged first to fill the syphon with liquor, and then invert it?

*Father.* No: a small pipe is fixed to the outer leg of the syphon, by which the air is drawn out of it by the mouth, and the short leg being immersed in the wine, the fluid will follow the air, and run out till the bottle is empty.

The syphon is sometimes disguised for the sake of amusing young people. Tantalus's cup (Plate III. Fig. 27.) is of this kind. The longer leg of the syphon passes through, and is cemented into the bottom of the cup: if water be poured into the cup, so as not to stand so high as

the bend of the tube, the water will remain as in any common vessel; but if it be raised over the bended part of the syphon, it will run over, and continue to run till the vessel is emptied. Sometimes a little figure of a man, representing Tantalus, conceals the syphon, so that Tantalus, as in the fable, stands up to his chin in water, but is never able to quench his thirst, for just as it comes to a level with his chin, it runs out through the concealed-syphon.

*Emma.* To this fable the lines in Pope's Homer refer :

Even in the circling floods refreshment craves,  
And pines with thirst amidst a sea of waves ;  
And when the water to his lips applies,  
Back from his lips the treacherous water flies.

POPE.

*Father.* It is alluded to also by our own Milton :

The ford, and of itself the water flies  
All taste of living wight, as once it fled  
The lip of Tantalus. —————

Par. Lost, Book II.

This is another kind of Tantalus's cup, (Plate IV. Fig. 28.) but the syphon is concealed in the handle, and when the water in the cup, which communicates with the shorter leg at c, is raised above the bend of the handle, it runs out through the longer leg at r, and so continues till the cup is empty. This cup is often made to deceive the unwary, who, by taking it up to drink, cause the water, which was, while at rest, below the bend of the syphon, to run over, and then there is no means of

stopping the stream till the vessel is empty.

*Charles.* I have frequently seen at the doors of public houses large hogsheads of spirits in carts or wag-gons, and persons drawing off the contents by means of an instrument like a syphon.

*Father.* That is called a distiller's crane or syphon. B (Plate IV. Fig. 29.) represents one of these barrels with the crane at work from the bung-hole *n*. The longer leg *m r* is about three feet long, with a stop-cock near the middle, which must be shut, and then the shorter leg is immersed in the liquor.

*Emma.* Then by the upward pressure of the fluid, the air in the short leg is forced into the other.

*Father.* And the cock being shut it cannot escape, but will be very much condensed. If then the cock be suddenly opened, the condensed air will rush out, and the pressure of the air on the liquor in the vessel will force it over the bend of the syphon, and ~~cause~~ it to flow off in a stream, as the figure represents. If, however, the barrel be not full, or nearly so, then it is necessary to draw the air out of the syphon by means of a small tube, *a b*, fixed to it.

By the principle of the syphon we are enabled to explain the nature of intermitting springs.

*Emma.* What are these, Papa?

*Father.* They are springs, or rather streams, that flow periodically. A figure will give a clearer idea of the subject than many words without.

*G F C* (Plate IV. Fig. 30.) represent a cavity in the bowels of a hill, or mountain, from the bottom of which, *c*, proceeds the irregular cavity *c E D*, forming a sort of natural syphon. Now, as this cavity fills, by means of rain or snow draining through the pores of the ground, the water will gradually rise in the leg *c E*, till it has attained the horizontal level *h h*, when it will begin to flow through the leg *E D*, and continue to increase in the quantity discharged as the water rises higher, till a full stream is sent forth, and then, by the principle of the syphon, it must continue to flow till the water sink to the level *i i*, when the air will rush into the syphon, and stop its motion.

*Charles.* And being once brought so low, it cannot run over again till

the cavity is full of water, or, at least, up to the level  $h h$ , which, as it is only supplied by the draining of the water through the ground, must take a considerable length of time : Is that the reason why they are called intermitting springs ?

*Father.* It is : Mr. Clare, in his treatise “ On the Motion of Fluids,” illustrates this subject by referring to a pond at Gravesend, out of which the water *ebbs* all the time the tide is coming into the adjacent river, and runs in while the tide is going out. Another instance mentioned by the same author is a spring in Derbyshire, called the Wedding-well, which, at certain seasons, issues forth a strong stream, with a singing noise, for about three minutes, and then stops again. At Lambourn, in Berk-

shire, there is a brook which in summer carries down a stream of water sufficient to turn a mill; but during the winter there is scarcely any current at all.

In intermitting springs the periodical returns of the flowing and cessation will be regular, if the filling of the reservoir be so; but the interval of the returns must depend on the quantity of water furnished by the springs.

## CONVERSATION XIX.

---

*Of the Diver's Bell.*

*FATHER.* Take this ale-glass, and thrust it with the mouth downwards into a glass jar of water, and you will perceivé that but very little water will enter into it.

*Charles.* The water does not rise in it more than about a quarter of an inch: if I properly understand the subject, the air, which filled the glass before it was put in water, is now compressed into the smaller space; and it is this body of air that

prevents more water getting into the glass.

*Father.* That is the reason: for if you tilt the glass a little on one side, a part of the air will escape in the form of a bubble, and then the water will rise higher in the glass.

Upon this simple principle machines have been invented, by which people have been able to walk about at the bottom of the sea, with as much safety as upon the surface of the earth. The original machine of this kind was much improved by Dr. Halley, more than a century ago: it was called the Diver's Bell.

*Charles.* Was it made in the shape of a bell?

*Father.* It was; and as great strength was required to resist the pressure of the water, he caused it

to be made of copper: this (Plate IV. Fig. 31.) is a representation of it. The diameter of the bottom was five feet, that of the top three feet, and it was eight feet high: to make the vessel sink vertically in water, the bottom was loaded with a quantity of leaden balls.

*Emma.* It was as large as a good sized closet; but how did he contrive to get light?

*Father.* Light was let into the bell by means of strong spherical glasses, fixed in the top of the machine. They are thus described by Dr. Darwin:

—————Lo! Britain's sons shall guide  
Huge Sea-balloons beneath the tossing tide;  
'The *diving* castles, roof'd with spheric glass,  
Ribb'd with strong oak, and barr'd with bolts  
of brass.

BOTANICAL GARDEN.

*Charles.* How are the divers supplied with air?

*Father.* Barrels, filled with fresh air, were made sufficiently heavy, and sent down, such as that represented by c; from which a leathern pipe communicated with the inside of the bell, and a stop cock at the upper part of the bell let out the foul air. Dr. Darwin, in the spirit of prophecy, anticipates the time when these machines will be sent out upon voyages of discovery, and says,

Then shall BRITANNIA rule the wealthy realms,  
Which Ocean's wide insatiate wave o'erwhelms;  
Confinè in netted bowers his scaly flocks,  
Part his blue plains, and people all his rocks.

BOTANICAL GARDEN.

*Emma.* The little men seem to sit very contentedly under the bell,

yet I do not think I should like a journey with them.

*Father.* Perhaps not: but the principal inconvenience which divers experience arises from the condensation of the air in the bell, which though in the alc-glass was very trifling, yet at considerable depths in the sea is very great, and produces a disagreeable pressure upon all parts of the body, but more particularly in their ears, as if quills were thrust into them. This sensation does not last long, for the air pressing through the pores of the skin, soon becomes as dense within their bodies as without, when the sense of pressure ceases.

*Emma.* They might stop their ears with cotton.

*Father.* One of them once thought himself as cunning as you, and for the want of cotton he chewed some paper, and stuffed it into his ears; as the bell descended, the paper was forcibly pressed into the cavities, and it was with great difficulty and some danger that it was extracted by a surgeon.

*Charles.* Are divers able to remain long under water?

*Father.* Yes: when all things are properly arranged, if business require it, they will stay several hours without the smallest difficulty.

*Emma.* But how do they get up again?

*Father.* They are generally let down from on board ship, and taking a rope with them, to which is fixed a bell in the vessel, they have

only to pull the string, and the people in the ship draw them up.

*Charles.* What does the figure E represent?

*Father.* A man detached from the bell, with a kind of inverted basket made of lead, in which is fixed another flexible leathern pipe, to give him fresh air from the bell as often as he may find it necessary. By this method a man may walk to the distance of 80 or 100 yards from the machine.

*Emma.* It is to be hoped his comrades will not forget to supply him with air.

*Father.* If his head is a little above that part of the bell to which the pipe communicates, he can by means of a stop-cock assist himself as often as he requires a new supply ;

and that man is always best helped who can help himself.

*Charles.* I dare say that is a right principle; in the pre-ent case. I am sure, it would be exceedingly wrong to depend on another for that which might be done by one's self. Has the Diver's Bell been applied to any very useful purposes?

*Father.* By means of this invention, a great number of valuable commodities have been recovered from wrecks of ships, though at great depths in the sea.

## CONVERSATION XX.

---

*Of the Diver's Bell.*

*FATHER.* You see how, by this contrivance, the parts of wrecked vessels and their cargoes are saved from the devouring ocean; and by what means people are enabled to pursue the business of pearl and coral fishing.

*Emma.* Have there been no accidents attending this business?

*Father.* There are very few professions, however simple, the exercise of which, either through carelessness or inattention, is not attended with

danger. The diving-bell proved fatal to Mr. Spalding and an assistant, who went down to view the wreck of the Imperial East-Indiaman near Ireland. They had been down twice, but on descending the third time they remained about an hour under water, and had two barrels of air sent down to them, but on signals from below not being again repeated, after a certain time they were drawn up by their assistants, and both found dead in the bell. This accident happened by the twisting of some ropes, which prevented the unfortunate sufferers from announcing their wants to their companions in the ship.—Mr. Day also perished at Plymouth in a diving-bell of his own construction, in which he was to have continued, for a wager, twelve

hours, one hundred feet deep in water. To these Dr. Darwin alludes; when speaking of the sea he says,

Mingling in death the brave and good behold,  
With slaves to glory, and with slaves to gold,  
Shrin'd in the deep shall DAY and SPALDING  
mourn,

Each in his treacherous bell, sepulchral urn!

BOTANICAL GARDEN.

*Charles.* Did these accidents put an end to the experiments?

*Father.* They have led to improvements in the structure and use of the machine. Mr. Smeaton very successfully made use of a square cast-iron chest, (Plate IV. Fig. 32.) the weight of which, 50 cwt., was heavy enough to sink itself. It was  $4\frac{1}{2}$  feet in height, the same number of feet in length, and 3 feet wide,

and of course afforded sufficient room for two men to work under it at a time.

*Emma.* What are those round things at the top?

*Father.* They are four strong pieces of glass to admit the light. The great advantage which this had above Dr. Halley's bell, was, that the divers were supplied with a constant influx of air, without any attention of their own, by means of a forcing air-pump, worked in a boat upon the water's surface.

*Charles.* That is not represented in the plate.

*Father.* Look to the next figure, (Plate IV. Fig. 33.) which is a diving machine of a different construction, invented by the very ingenious and truly respectable lecturer, Mr.

Adam Walker\*, by whose leave I am enabled to copy the figure.

This machine is of the shape of a conical tub, but little more than one-third as large as Mr. Smeaton's. The balls at the bottom are lead, sufficiently heavy to make it sink of itself: a bended metal tube, *a b c*, is attached to the outside of the machine with a stop-cock *a*, and a flexible leathern tube to the other end *c*; this tube is connected with a forcing air-pump *d*, which abundantly supplies the diver with fresh air.

*Emma.* Can he move about with the machine?

*Father.* Most readily; for the pressure of the water being equal on

\* See Walker's System of Natural Philosophy, 2 Vols. 4to.

all sides, he meets with very little resistance; and the ropes and leather tube being flexible, he can, with the machine over his head, walk about several yards, in a perpendicular posture; -and thus having a more ready access to pieces of the wreck than in a cumbrous bell, he can easily fasten ropes to them, and perform any sort of business nearly as well as on dry land. Mr. Walker says, that the greatest part of the wreck saved from the rich ship *Belgioso* was taken up by means of this bell. The following anecdote, given by this gentleman, will entertain my young readers.

“As the diver had plenty of air to spare, he thought a candle might be supported in the bell, and he could descend by night. He made

the experiment, and presently found himself surrounded by fish, some very large, and many such as he had never seen before. They sported about the bell, and smelt at his legs as they hung in the water : this rather alarmed him, for he was not sure but some of the larger might take a fancy to him : he therefore rang his bell to be taken up, and the fish accompanied him with much good nature to the surface.”—To a scene not very unlike this, Dr. Darwin refers in the spirit of prophecy, when,

Onward, thro’ bright meandering vales, afar,  
Obedient sharks shall trail her scepter’d car,  
With harness’d necks the pearly flood disturb,  
Stretch the silk rein, and champ the silver curb ;  
Pleas’d round her triumph wond’ring Tritons  
play,

And sea-maids hail her on the wat’ry way.

BOTANICAL GARDEN.

## CONVERSATION XXI.

---

*Of Pumps.*

*FATHER.* Here is a glass model of a common pump (Plate IV. Fig. 34.) which acts by the pressure of the atmosphere on the surface of the water in which it is placed.

*Emma.* Is this like the pump below stairs?

*Father.* The principle is exactly the same: *a* represents a ring of wood, or metal, with pliable leather fastened round it to fit the cylinder *A*. Over the whole is a valve of metal covered with leather, of which

a part serves as a hinge for the valve to open and shut by.

*Charles.* What is a valve, Sir?

*Father.* It may be described as a kind of lid or trap-door, that opens one way into a tube, but which the more forcibly it is pressed the other way, the closer the aperture is shut: so that it either admits the entrance of a fluid into the tube, and prevents its return; or permits it to escape, and prevents its re-entrance.

Attend now to the figure: the handle and rod *r* end in a fork *s*, which passes through the piston, and is screwed fast to it on the under side. Below this, and over a tube of a smaller bore, as *z*, is another valve *v* opening upward, which admits the water to flow up, but not to run down.

*Emma.* That valve is open now, by which we see the size of the lower tube, but I do not perceive the upper valve.

*Father.* It is supposed to be shut, and in this situation the piston *a* is drawn up, and being air-tight, the column of air on its top is removed, and consequently leaves a vacuum in the part of the cylinder between the piston and the lower valve.

*Charles.* I now see the reason of lifting up the handle to pump: because the piston then goes down to the lower valve, and by its ascent afterwards the vacuum is produced.

*Father.* And the closer the piston is to the lower valve the more perfect will be the vacuum.

You know there is a pressure of the air on all bodies on or near the sur-

face of the earth, equal to about 14 or 15 pounds on every square inch : this pressure upon the water in the well, into which the lower end of the pump is fixed, forces the water into the tube  $z$  above its level as high as  $l$ .

*Charles.* What becomes of the air that was in that part of the tube ?

*Father.* You shall see the operation : I will put the model into a dish of water which now stands at a level in the tube  $z$ , with the water in the dish. I draw up the piston  $a$ , which causes a vacuum in the cylinder  $A$ .

*Emma.* But the valve  $v$  opens, and now the water has risen as high as  $l$ .

*Father.* Because when the air was taken out of the cylinder  $A$ , there

was no pressure upon the valve  $v$  to balance that beneath it, consequently the air in the tube  $z$  opens its valve  $v$ , and part of it rushed into  $a$ . But as soon as part of the air had left the tube  $z$ , the pressure of the atmosphere upon the water in the dish was greater than that of the air in the tube, and therefore by the excess of pressure the water is driven into it as high as  $l$ .

*Charles.* The valve  $v$  is again shut.

*Father.* That is, because the air is diffused equally between the level of the water at  $l$  and the piston  $a$ , and therefore the pressures over and under the valve are equal. And the reason that the water rises no higher than  $l$  is, that the air in that space is not only equally diffused, but is of

the same density as the air without. Push down the piston *a* again.

*Emma.* I saw the valve in the piston open.

*Father.* For the air between the piston and valve *v* could not escape by any other means than by lifting up the valve in *a*. I will draw up the piston.

*Charles.* The water has risen now above the valve *v* as high as *m*.

*Father.* I dare say you can tell the cause of this.

*Charles.* Is it this : by lifting up the piston, the air that was between *l* and the valve *v* rushed into *A*, and the external pressure of the atmosphere forced the water after it?

*Father.* And now that portion of air remains between the surface of the water *m* and the piston. The

next time the piston is forced down, all the air must escape, the water will get above the valve in the piston, and, in raising it up again, it will be thrown out of the spout.

*Emma.* Will the act of throwing that out open the lower valve again, and bring in a fresh supply ?

*Father.* Yes : every time the piston is elevated, the lower valve rises, and the upper valve falls ; but every time the piston is depressed, the lower valve falls, and the upper one rises.

*Emma.* This method of raising water is so simple and easy, that I wonder people should take the trouble of drawing water up from deep wells, when it might be obtained so much easier by a pump.

*Father.* I was going to tell you, that the action of pumps, so beauti-

ful and simple as it is, is very limited in its operation. If the water in the well be more than 32 or 33 feet from the valve *v*, you may pump for ever, but without any effect.

*Charles.* That seems strange; but why 33 feet in particular?

*Father.* I have already told you that it is the weight of the atmosphere which forces the water into the vacuum of the pump: now if this weight were unlimited, the action of the pump would be so likewise; but the weight of the atmosphere is only about 14 or 15 pounds on every square inch; and a column of water, of about 33 feet in height, and whose surface is one square inch, weighs also 14 or 15 pounds.

*Charles.* Then the weight of the atmosphere would balance or keep in equilibrio only a column of water of 33 feet high, and consequently could not support a greater column of water, much less have power to raise it up.

*Emma.* A pump, then, would be of no use in the deep wells which we saw near the coast in Kent.

*Father.* None at all : the piston of a pump should never be set to work more than 28 feet above the water, because at some periods the pressure of the atmosphere is so much less than at others, that a column of water, something more than 28 feet, will be equal to the weight of the air.

You cannot better fix in your mind the principle and action of the pump, than by committing to your

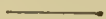
memory Dr. Darywin's beautiful description of it :

NYMPHS ! You first taught to pierce the secret  
caves

Of humid earth, and lift her pond'rous waves ;  
Bade with quick stroke the sliding piston bear  
The viewless columns of incumbent air ;—  
Press'd by the incumbent air, the floods below  
Thro' opening valves in foaming torrents flow ;  
Foot after foot with lessen'd impulse move,  
And rising, seek the vacancy above.

BOTANIC GARDEN.

## CONVERSATION XXII.



*Of the Forcing-pump—Fire-engine—  
Rope-pump—and Water-press.*

*CHARLES.* Why is this called the forcing-pump? (Plate IV. Fig. 35.)

*Father.* Because it not only raises the water into the barrel like the common pump, but afterwards forces it up into the reservoir K K.

*Emma.* How is that operation performed, Papa?

*Father.* The pipe and barrel are the same as in the other pump, but the piston has no valve; it is so

lid and heavy, and made air-tight, so that no water can get above it.

*Charles.* Does the water come up through the valve *a*, as it did in the last?

*Father.* By raising up the piston, or, as it is generally called, the plunger *g*, a vacuum is made in the lower part of the barrel, into which, by the pressure of the air, the water rushes from the well, as you shall see.

*Emma.* And the valve is shut down.

*Father.* The water not being able to go back again, and being a fluid that is nearly incompressible, when the plunger is forced down, it escapes along the pipe *m*, and through the valve *b* into the vessel *k*.

*Charles.* Though the water stands no higher than  $h$ , yet it flows through the pipe  $F$  to some height.

*Father.* The pipe  $F i$  is fixed into the top of the vessel, and is made air-tight, so that no air can escape out of it after the water is higher than  $i$ , the edge of the pipe.

*Emma.* Then the whole quantity of air which occupied the space  $F b$  is compressed into the smaller space  $h F$ .

*Father.* You are right, and therefore the extra pressure on the water in the vessel forces it through the pipe, as you see.

*Charles.* And the greater the condensation; that is, the more water you force into the vessel  $K$ , the higher the stream will mount.

*Father.* Certainly : for the forcing-pump differs from the last in this respect, that there is no limit to the altitude to which water may be thrown, since the air may be condensed to almost any degree.

The water-works at London bridge, alluded to p. 101, exhibit a most curious engine, constructed upon the principle of the forcing-pump : the wheel-work is so contrived as to move either way as the water runs : by these works 140,000 hogsheads of water are raised every day.

*Emma.* Is there any rule to calculate the height to which an engine will throw water ?

*Father.* If the air's condensation be double that of the atmosphere, its pressure will raise water 33 feet ; if the condensation be increased three-

fold, the water will reach 66 feet ; and so on, allowing the addition of 33 feet in height for every increase of *one* to the number that expressed the air's condensation.

*Charles.* Are fire-engines made in this manner ?

*Father.* They are all constructed on the same principle, but there are two barrels by which the water is alternately driven into the air-vessel : by this means the condensation is much greater ; the water rushes out in a continued stream, and with such velocity, that a raging fire is rather dashed out than extinguished by it, which is well described in the Botanic Garden :

NYMPHS ! You first taught the gelid wave to  
rise,

Hurl'd in resplendent arches to the skies ;

In iron cells condens'd the airy spring,  
And imp'd the torrent with unfailing wing.  
—On the fierce flames the shower impetuous  
falls, [walls;  
And sudden darkness shrouds the shatter'd  
Steam, smoke, and dust, in blended volumes roll,  
And night and silence re-possess the Pole.

Garden-engines are also constructed on a principle similar to that we have been describing.

This figure (Plate IV. Fig. 36.) is the representation of a method of raising water from wells of considerable depth.

*Emma.* Is it a more convenient method than the wheel and axis?

*Father.* The wheel and axis are adapted merely to draw up water by buckets: whereas the rope-pump is intended to throw water into a reservoir to almost any height. It consists

of three hair ropes passing over the pulleys A and B, which have three grooves in each. The lower pulley B is immersed in the water, in which it is kept suspended by a weight  $x$ . The pulleys are turned round with great velocity by multiplying wheels, and the cords in their ascent carry up a considerable quantity of water, which they discharge into the box or reservoir  $z$ , from whence by pipes it may be conveyed elsewhere. The ropes must not be more than about an inch apart.

*Emma.* What is the reason of that, Papa?

*Father.* Because, in that case, a sort of column of water will ascend between the ropes, to which it adheres by the pressure of the atmosphere.

*Charles.* Ought not this column, in its ascent, to fall back by its own gravity?

*Father.* And so it would, did not the great velocity of the ropes occasion a considerable rarefaction of the air near them, consequently the adjacent parts of the atmosphere pressing towards the vacuity, tend to support the water.

*Emma.* Can any considerable quantity of water be raised in this way?

*Father.* At Windsor a pump of this kind will raise, by the efforts of one man, about 9 gallons of water in a minute from a well 95 feet deep. In the beginning of motion, the column of water adhering to the rope is always less than when it has been worked for some time, and the quan-

tity continues to increase till the surrounding air partake of its motion. There is also another of these pumps at the same place, which raises water from the well in the round tower 178 feet in depth.

*Charles.* You told us some time ago, that when we had seen the nature and understood the construction of valves, you would explain the action of the water-press.

*Father.* This is a good time for the purpose, and with it I shall conclude our hydrostatical conversations.

You must turn back to the second Plate (Fig. 14). *a* is a strong cast-iron cylinder, ground very accurately within, that the piston *e* may fit exceedingly close and well. I need scarcely tell you, that the little figure represents a forcing-pump, with a so-

lid plunger  $c$ , and a valve  $n$  that opens upwards, through which the water is brought into the pipe  $n o$ . By bringing down the plunger  $c$ , the water in  $n o$  is forced through the valve  $x$  into the bottom of the cylinder, and thereby drives up the plunger  $e$ .

*Charles.* What does  $m$  represent?

*Father.* A bundle of hay, or bag of cotton, or any other substance that it may be desirable to bring into a compass twenty or thirty times less than it generally occupies.

*Emma.* I see now the whole operation: the more water there is forced into  $e o$ , the higher the plunger is lifted up, by which the substance  $m$  is brought into a smaller space.

*Father.* Every time the handle  $s$  is lifted up the water rushes in from the well or cistern, and when it is

brought down the water must be forced into the cylinder. The power of this engine is only limited by the strength of the materials of which it is made, and by the force applied to it.

Mr. Walker says, a single man, working at s, can, by a machine of this kind, bring hay, cotton, &c. into twenty times less compass than it was before; consequently a vessel carrying light goods may be made to contain twenty times more packages by means of the water-press, than it could without its assistance.

END OF THE THIRD VOLUME.

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Fig. 4.

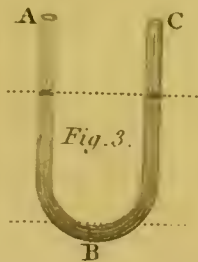


Fig. 1.



Fig. 7.

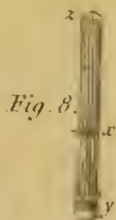
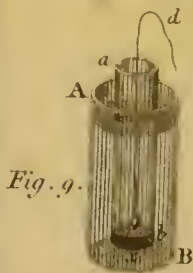
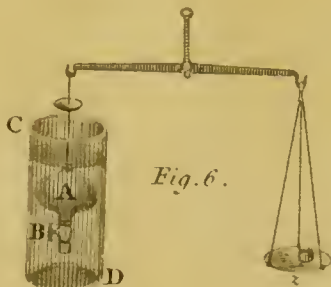


Fig. 8.

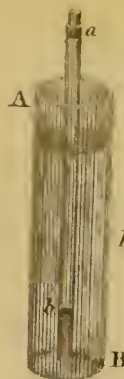


Fig. 5.

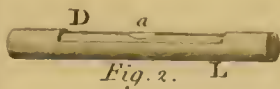


Fig. 2.





Fig. 12.

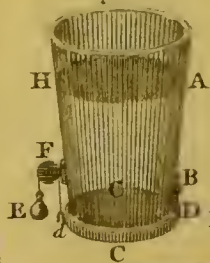


Fig. n.

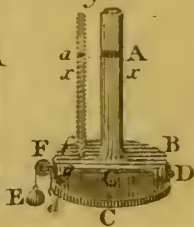


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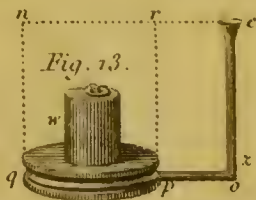
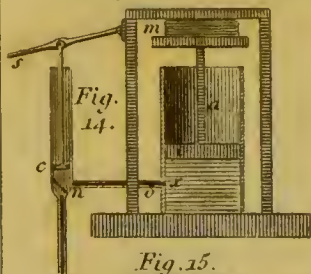
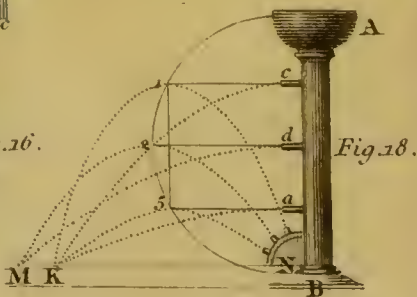
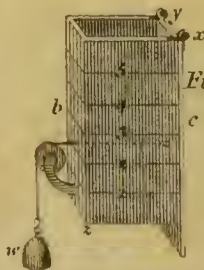
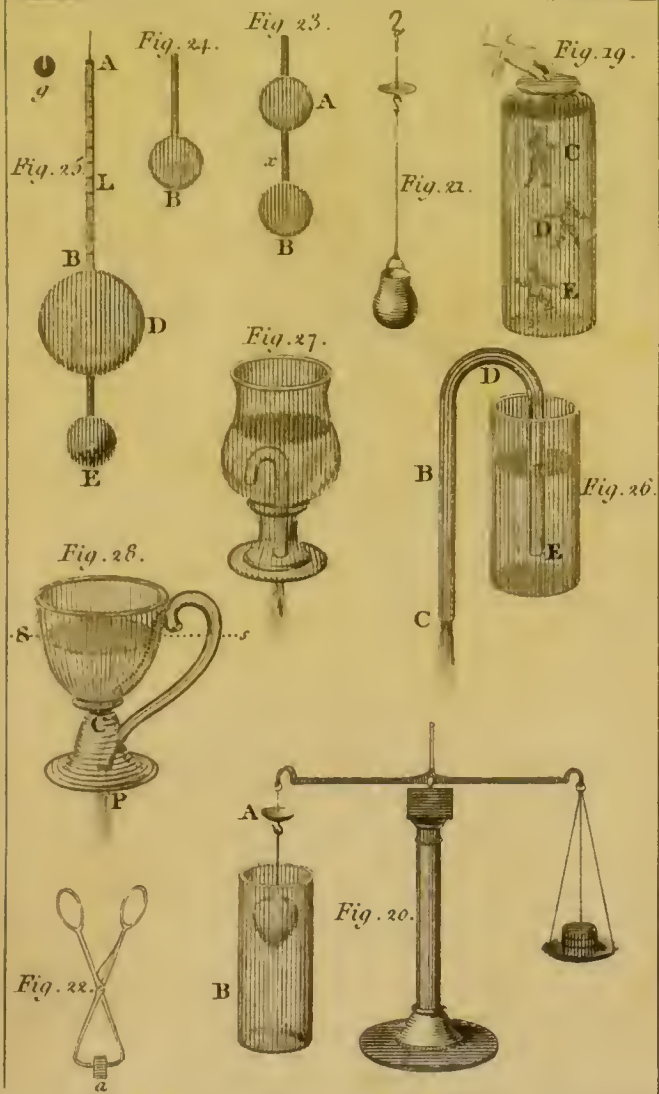


Fig. 15.



Fig. 16.









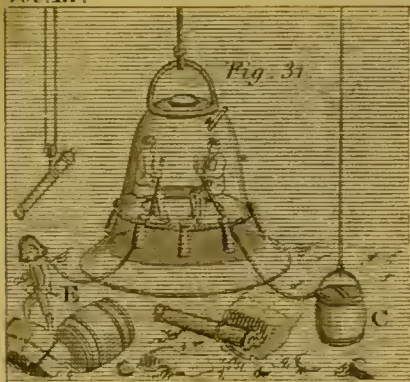


Fig. 36.

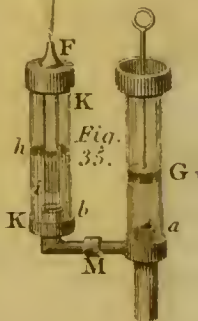


Fig. 35.

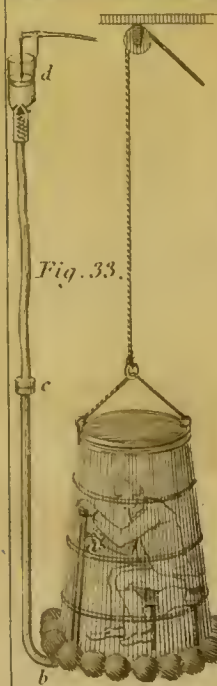
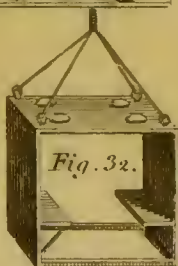


Fig. 33.



Fig. 29.



Fig. 30.

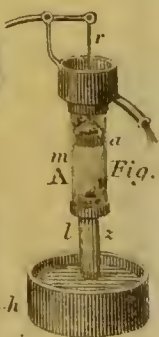


Fig. 34.







